# TREATISE ON CERAMIC INDUSTRIES

EMILE BOURRY

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# Treatise on Ceramic Industries

*A COMPLETE MANUAL FOR POTTERY, TILE AND BRICK WORKS*

BY

EMILE BOURRY

INGÉNIEUR DES ARTS ET MANUFACTURES

TRANSLATED FROM THE FRENCH

BY

WILTON P. RIX

EXAMINER IN POTTERY AND PORCELAIN TO THE CITY AND GUILDS OF LONDON TECHNICAL INSTITUTE

POTTERY INSTRUCTOR TO THE HANLEY SCHOOL BOARD

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## TRANSLATOR'S PREFACE.

No apology is needed in the present instance for the publication of this work. The lack of technical treatises in the English language devoted to Ceramic Industry has long been a serious drawback to the progress alike of the student and the manufacturer. Since the days of Simeon Shaw there has been no serious attempt by any English writer to grapple with the complex problems of ceramics, or to produce any comprehensive description of the processes of clay manipulation. In view of this fact, and also that during the last few years an increasing interest has been manifested in systematic ceramics, it has been felt that the issue of such a work might prove opportune.

Preference has been given to M. Bourry's work for translation on several grounds, but chiefly because it appeared likely to be of more substantial benefit to the practical potter. To the busy worker the exhaustive and original researches of Seger demand more time for study than can be devoted to such matters. On the other hand, the works of Brongniart seemed to lack the perspicuous classification and concise method of statement which is one of the happiest features of M. Bourry's able book. Unlike all other works, it also treats with equal fulness the manipulation of every class of ceramics from the common brick to the finest porcelain, and thus enables the reader to compare the effect of the general

principles governing the results of most diverse manufactures.

From the engineer's point of view the work should also prove useful, giving as it does a discriminating selection of the best known machines and appliances from makers in various countries.

Bearing in mind that the book is intended as a manual for practical men rather than a hand-book for the scientist, no attempt has been made in translating to revise the chemical nomenclature except where the subject seemed to be of purely scientific interest. In most cases the popular names of chemicals have been retained. The translator has met with the usual difficulty in finding English equivalents for many appliances and processes owing to the fact that the English terms used in one district for these are entirely different from those of another. In such instances it has been considered better to adopt some general descriptive word which, though less technical, could be more readily understood by all. Occasionally, where the statement depends on a complex series of mathematical deductions based on French calculations, it has been found preferable to allow these to stand untranslated when the principles deduced are unaffected thereby.

Various developments have caused an increasing necessity for a full knowledge and scientific grasp of the principles governing ceramics. The discovery of the methods necessary to the successful manufacture of pottery is to a large extent complete, and competition no longer runs severely in the direction of acquiring fresh ones. The research of the future will be chiefly directed to the perfecting of processes already discovered, and in establishing a more complete control and manipulation of the materials already in use. Nor is the desire

for such information the only reason for the evident need of more technical knowledge. The progress of science, and the development of chemistry, electricity and hygiene, have caused a much greater demand on the potter's resources in the output as well as in the quality of his wares. Almost every new branch of industry *now* requires the use of ceramic material in some form, and in nearly all accuracy of detail in shape, composition, strength, non-conduction, non-absorption, resistance to heat or to chemical action, are of the utmost importance. Realising this demand for accuracy and efficiency in the techniques of this manufacture, continental experts have provided pottery makers with the most complete information, both scientific and practical, by publishing the results of their research. Nor has this been left entirely to individual efforts, the respective governments assisting either directly or indirectly the students and factories in which such inquiries have been carried on.

Quite lately, and very gradually, the English and American manufacturers have awakened to the importance of basing their operations upon more systematic and scientific methods, and it is hoped that the present work may prove of some assistance towards this result.

It is hardly necessary here to enter into the reasons for the insular reticence so characteristic of the Englishman which have induced him to keep to himself technical experience probably gained by many painful efforts, and at the expense of much loss through lack of more accurate knowledge. Failing to recognise that there is much which is technically common to all pottery manufacture, he has imagined that his experiences were unique, and, therefore, to be kept absolutely secret. Hitherto the English potter's work has been far too empirical,

and though many of the operations and the formulæ are based upon the survival of the fittest, the conclusions arrived at have not been founded upon sufficiently accurate knowledge of the principles involved. There is little doubt that it would greatly add to the general progress of the industry in this country if manufacturers were able to combine in pursuing such technical research as related to subjects and methods common alike to all their manufactures, leaving to each the opportunity of specialising in the details peculiar to his own section. By this means much unnecessary labour and expense would be avoided, and the advantage thereby gained must be apparent.

WILTON P. RIX.

LIVERPOOL ROAD,
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*September*, 1901.

# CONTENTS.

PAGE

Translator's Preface . . . . . iii

## FIRST PART.

## GENERAL POTTERY METHODS.

### CHAPTER I.

DEFINITION AND HISTORY.

Definitions and Classification of Ceramic Products — Historic Summary of the Ceramic Art . . . . . 1

### CHAPTER II.

RAW MATERIALS OF BODIES.

Clays: Pure Clay and Natural Clays.

Various Raw Materials: Analogous to Clay—Agglomerative and Agglutinative—Opening—Fusible—Refractory.

Trials of Raw Materials . . . . . 44

### CHAPTER III.

PLASTIC BODIES.

Properties and Composition.

Preparation of Raw Materials: Disaggregation—Purification.

Preparation of Bodies: By Plastic Method—By Dry Method—By Liquid Method . . . . . 100

### CHAPTER IV.

FORMATION.

Processes of Formation: Throwing—Expression—Moulding by Hand, on the Jolley, by Compression, by Slip Casting—Slapping—Slipping . . . . . 182

### CHAPTER V.

DRYING.

Drying of Bodies.

Processes of Drying: By Evaporation—By Aeration—By Heating—By Ventilation—By Absorption . . . . . 238

## CHAPTER VI.

### Glazes.

PAGE

Composition and Properties—Raw Materials—Manufacture and Application . . . . . 272

## CHAPTER VII.

### Firing.

Properties of the Bodies and Glazes during Firing—Description of the Kilns—Working of the Kilns . . . . . 299

## CHAPTER VIII

### Decoration.

Colouring Materials—Processes of Decoration . . . . . 407

# SECOND PART.

# SPECIAL POTTERY METHODS.

## CHAPTER IX.

### Terra Cottas.

Classification: Plain Ordinary, Hollow, Ornamental, Vitrified, and Light Bricks—Ordinary and Black Tiles—Paving Tiles—Pipes—Architectural Terra Cottas—Vases, Statues and Decorative Objects—Common Pottery—Pottery for Water and Filters—Tobacco Pipes—Lustre Ware.

Properties and Tests for Terra Cottas . . . . . 447

## CHAPTER X.

### Fireclay Goods.

Classification: Argillaceous, Aluminous, Carboniferous, Silicious, and Basic Fireclay Goods—Fireclay Mortar (Pug).

Tests for Fireclay Goods . . . . . 568

## CHAPTER XI.

### Faiences.

Varnished Faiences—Enamelled Faiences—Silicious Faiences—Pipeclay Faiences—Pebble Work—Feldspathic Faiences.

Composition, Processes of Manufacture and General Arrangements of Faience Potteries . . . . . 598

## CHAPTER XII.

### Stoneware.

PAGE

Stoneware properly so called: Paving Tiles—Pipes—Sanitary Ware—Stoneware for Food Purposes and Chemical Productions—Architectural Stoneware—Vases, Statues and other Decorative Objects.

Fine Stoneware . . . . . 660

## CHAPTER XIII.

### Porcelain.

Hard Porcelain for Table Ware and Decoration, for the Fire, for Electrical Conduits, for Mechanical Purposes; Architectural Porcelain, and Dull or Biscuit Porcelain—Soft Phosphated or English Porcelain—Soft Vitreous Porcelain, French and New Sèvres—Argillaceous Soft or Seger's Porcelain—Dull Soft or Parian Porcelain—Dull Feldspathic Soft Porcelain . . . . . 700

Index . . . . . 739

---

The Metric and British Systems Compared . . . . . x

Comparison between Fahrenheit and Centigrade Thermometers . x

# THE METRIC AND BRITISH SYSTEMS.

## TABLE OF COMPARISON.

| Metres. | Deci metres. | Centi-metres. | Milli-metres. | Inches. | Metres. | Deci-metres. | Centi-metres. | Milli-metres. | Inches. |
|---|---|---|---|---|---|---|---|---|---|
| ·001 | ·01 | ·1 | 1 | ·039 | ·06 | ·6 | 6 | 60 | 2·362 |
| ·002 | ·02 | ·2 | 2 | ·079 | ·07 | ·7 | 7 | 70 | 2·756 |
| ·003 | ·03 | ·3 | 3 | ·118 | ·08 | ·8 | 8 | 80 | 3·150 |
| ·004 | ·04 | ·4 | 4 | ·157 | ·09 | ·9 | 9 | 90 | 3·543 |
| ·005 | ·05 | ·5 | 5 | ·197 | ·1 | 1 | 10 | 100 | 3·94 |
| ·006 | ·06 | ·6 | 6 | ·236 | ·2 | 2 | 20 | 200 | 7·87 |
| ·007 | ·07 | ·7 | 7 | ·276 | ·3 | 3 | 30 | 300 | 11·81 |
| ·008 | ·08 | ·8 | 8 | ·315 | ·4 | 4 | 40 | 400 | 15·75 |
| ·009 | ·09 | ·9 | 9 | ·354 | ·5 | 5 | 50 | 500 | 19·69 |
| ·01 | ·1 | 1 | 10 | ·394 | ·6 | 6 | 60 | 600 | 23·62 |
| ·02 | ·2 | 2 | 20 | ·787 | ·7 | 7 | 70 | 700 | 27·56 |
| ·03 | ·3 | 3 | 30 | 1·181 | ·8 | 8 | 80 | 800 | 31·50 |
| ·04 | ·4 | 4 | 40 | 1·575 | ·9 | 9 | 90 | 900 | 35·43 |
| ·05 | ·5 | 5 | 50 | 1·968 | 1 | 10 | 100 | 1,000 | 39·37 |

### Weight.

1 gramme = 15·44 grains.
28¼ grammes = 1 oz. avoird.
1 kilogramme = 1,000 ,, = 2·20 lb. avoird.

### Length.

1 metre = 100 centimetres = 39·37 inches. Roughly speaking, 1 metre = a yard and a tenth. 1 centimetre = two-fifths of an inch. 1 kilometre = 1,000 metres = five-eighths of a mile.

### Volume.

1 cubic metre = 1,000 litres = 35·32 cubic feet. 1 litre = 1,000 cubic centimetres ·2202 gall.

### Heat.

1 calorie = 3·96 British thermal units.

# COMPARISON BETWEEN FAHRENHEIT AND CENTIGRADE THERMOMETERS.

| C. | F. | C. | F. | C. | F. | C. | F. | C. | F. |
|---|---|---|---|---|---|---|---|---|---|
| −25 | −13 | 5 | 41 | 25 | 77 | 65 | 149 | 105 | 221 |
| 20 | −4 | 8 | 46·4 | 30 | 86 | 70 | 158 | 110 | 230 |
| −17 | 1·4 | 10 | 50 | 35 | 95 | 75 | 167 | 115 | 239 |
| −15 | 5 | 12 | 53·6 | 40 | 104 | 80 | 176 | 120 | 248 |
| 10 | 14 | 15 | 59 | 45 | 113 | 85 | 185 | 125 | 257 |
| 5 | 23 | 17 | 62·6 | 50 | 122 | 90 | 194 | 130 | 266 |
| 0 | 32 | 18 | 64·4 | 55 | 131 | 95 | 203 | 135 | 275 |
| 1 | 33·8 | 20 | 68 | 60 | 140 | 100 | 212 | 140 | 284 |

To Convert:—

Degrees C. to degrees F., multiply by 9, divide by 5, then add 32.
Degrees F. to degrees C., first substract 32, then multiply by 5 and divide by 9.

# FIRST PART.

## GENERAL POTTERY METHODS.

# CHAPTER I.

## DEFINITION AND HISTORY.

SUMMARY I.—*Definitions and Classification of Ceramic Products.*—Definitions—Division of the Work—General Principles of Classification—First Attempts at Classification — Brongniart's Classification — Various Classifications — Division into two Classes: Permeable and Impermeable Pottery—Division into Five Classes:

(1) Terra Cotta.
(2) Fired Refractory Clay.
(3) Earthenware (Faience).
(4) Stone Ware.
(5) Porcelain (China).

SUMMARY II.—*Historic Summary of the Ceramic Art.*—Ancient Fired Clay—Ancient Earthenware, Persian, Arabian, Moresque—Italian Earthenware — French Earthenware—German, Dutch and Various Earthenware—English Earthenware — Stone Ware — Oriental China — European China—Contemporary Ceramic Art.

### I. DEFINITIONS AND CLASSIFICATION OF CERAMIC WARE.

**1. Definitions.**—In nature we find a great number of rocks or earths which, when mixed with water, form plastic bodies which can be easily moulded into shape and can retain the shape given to them. These bodies, first dried, afterwards heated to a sufficiently high temperature, lose their plasticity and become hard bodies which cannot now be altered in shape. The minerals are designated under the general name of clays.

Clays, whether pure or mixed with other substances, by the addition of water and suitable preparation, form what is known in ceramic phraseology as "plastic bodies". They become "green ware" when they receive the form of the piece to be manufactured, and "biscuit" after they have been subjected to the process of firing, the word "body" having obtained in ceramics an illogical signification (but sanctioned by custom), designating both the plastic mass and the substance which has become hard through the firing.[1]

[1] Brongniart had suggested the word "excipient," which has not been adopted.

The green or fired ware can be covered over with a coating of "glaze," which vitrifies under the influence of heat, the object of this glaze being either to decorate the ware or to render it impermeable.

All the various kinds of ware obtained by these processes—bricks, tiles, flagstones, pipes, terra cotta, earthenware, stoneware, china—come under the general name of pottery[1] or ceramic ware.[2] They can be either simple or compound, that is to say, formed only of the body or composed of the body and the glaze.

The ceramic industries and arts are concerned with the manufacture and decoration of pottery ware. Their domain is as vast as it is varied, as much from the variety of the productions as from the multiplicity of the means which are employed for their manufacture. Ceramic productions in fact supply the most diverse needs of man. They enter as important factors into the construction and decoration of buildings; they supply the most varied domestic requirements; we find them indispensable for building of furnaces of all kinds, for the manufacture of chemical productions, for electric communication by pipes; they render important services to agriculture in the draining off of water; horticulture makes considerable use of them; the new science of hygiene has found in them an indispensable auxiliary, and finally they lend themselves to the creation of decorative pieces, uniting the art of sculpture to that of the painter. All these applications have made pottery an essential element of civilisation, of the same value as wood or metal, and more important than glass or natural stones.

The variety of application entails diversity in the methods employed in the manufacture. Sometimes the latter only requires the humble workshop of the potter, or the rudimentary shed of the brickmaker, whereas, at other times, it necessitates the use of large machines putting into action all the resources of industry and science. Again, sometimes the potter's aim is merely to produce a cheap piece of goods, at other times he aims at producing works of art in which the price of the raw material cannot equal a thousandth part of the value which the artist's talent has bestowed upon it.

[1] From the Latin *Potum*, *i.e.*, a drinking vessel.
[2] From the Greek κεράμος, *i.e.*, clay vase.

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However, notwithstanding the great variety of usage, processes and value, ceramic productions form a homogeneous and very distinct group in the midst of the other productions of industry and art, because their manufacture is in all cases based upon the properties of clay—in forming with water a plastic body which becomes hard under the influence of heat.

This definition clearly differentiates ceramic productions from glass, in which the plasticity necessary for shaping is obtained by a pasty fusion of the mass, and not by a cold shaping of a plastic body. This definition also distinguishes them from cements and other analogous agglomerated wares which harden by the holding together of the components, and not by the action of heat.

There are, however, two exceptions to this general definition.

(1) Certain china ware of which the body does not include clay, and which is properly termed "glass".

(2) Certain refractory wares in which clay is replaced by other agglutinants which really form part of the mass.

These wares are, however, classed as pottery, because they are manufactured by the usual processes employed in the manufacture of pottery.

**2. Division of the Work.**—The general study of ceramic industry is divided into two parts: the first deals with the principles and general processes of manufacture and decoration; the second deals with the description of the special processes of manufacture of the different kinds of pottery.

The first part is sub-divided into seven chapters. The first treats of the study of raw materials employed in the manufacture of bodies, and the six others bear on the six phases of manufacture of the most complex pottery.

(1) Preparation of plastic bodies, study of their properties, and the processes employed to disaggregate, purify, and mix the raw materials.

(2) Formation of these bodies, or processes employed to give shape to the pieces manufactured.

(3) Drying of the bodies so formed.

(4) Composition, raw materials, manufacture and laying on of the glaze.

(5) Firing of their bodies and glaze, study of their properties

during and after firing, description and working of the kilns employed for this purpose.

(6) Decoration of pottery, either by cutting off the body or by colouring the body or the glaze.

The second part naturally divides itself into five chapters corresponding to the five groups into which the ceramic productions can be classified:—

Terra cottas.
Refractory ware.
Earthenware.
Stoneware.
China.

The classification of ceramic ware would seem to have its logical place at the commencement of the second part; but as the various categories of pottery ware are necessarily mentioned in the first, this classification will be studied from the beginning of the work in order to explain the terminology employed.

It will be followed by a brief *résumé* of the history of the ceramic art.

**3. General Principles of Classification.**—The variety of ceramic productions renders it indispensable for a classification to be employed which will group under common designations all pottery ware having analogous properties. However, if the necessity of a classification is indisputable, it is easy to realise what difficulties will offer themselves.

Indeed, ceramic productions present themselves as a continuous series from the most common terra cotta to vitreous china, each product differing but slightly from that which preceded it, and from that which follows it, it being impossible to determine clearly the transition of the different categories. An example will serve to show this difficulty of determination. Terra cotta and stoneware are quite distinct articles of pottery, as much from the point of view of ceramic qualities as from their value. All Custom House rates impose on them unequal duties. Therefore we can understand that it is of interest to clearly differentiate them.

Now, in order to manufacture stoneware the heat must be raised to a sufficiently high temperature to cause vitrifaction of the body; if this degree is not attained, the ware is simply terra

cotta. If the temperature in the oven is not distributed uniformly, some pottery can be fired into stoneware, others into terra cotta, with all the intermediary stages. Some pieces even can be stoneware on one side and terra cotta on the other. Under these circumstances it is therefore inevitable that there should be divergencies of estimation, even among people who have large experience in the art of pottery.

Another difficulty of classification exists in the relative value which it is usual to attribute to the properties of the ware, a value which is not the same for different classes. Thus the chemical composition of a body which is relatively of secondary importance in terra cotta for building is of predominating importance in refractory fireclays. Besides, it matters little, ceramically speaking, whether a piece of stoneware has a coating of glaze or not, whereas a piece of pottery while unglazed is terra cotta, but becomes earthenware as soon as it possesses a glaze.

Therefore a general classification cannot be based on one determinate property without taking others into consideration. It cannot pretend to trace arbitrary lines of demarcation, and to distribute all pottery ware, past and future, into sharp divisions.

It should, therefore, confine itself to defining exactly the principal kinds of pottery, and to classifying those which, by the similarity of their properties, have most in common with each other.

Doubtless there will remain a few rare pieces of pottery which partake at the same time of the properties of two adjacent kinds, for which there will be an opportunity for indecision.

The latter will have little importance so long as these pieces of pottery remain exceptions, and if, through the progress of ceramics or the caprices of fashion, a few of them are more generally manufactured, it will be easy to make a new class for their kind, and they will always find a place of indication in the loose meshes of a sufficiently general classification.

The distinctive characteristics which serve to differentiate pottery ware can be divided into four classes:—

(1) Differences which are apparent in the physical properties, whether a body is vitreous or open, impermeable or permeable, transparent or opaque, hard or soft, white or coloured, fine or coarse grained, matt or glazed, the latter itself being hard or soft, transparent or opaque, etc.

(2) Differences in form and use.

(3) Differences in the chemical composition of the body and of the glaze.

(4) Differences in the process of the manufacture.

The differences of the first group are of the most importance from the point of view of classification.

They have not only the advantage of being easily and rapidly observed, but they enable the ceramist to judge beforehand of their chemical composition, and the mode of manufacture. Therefore they form the foundation of all classification of pottery ware.

From a purely theoretical point of view the differences of form and use ought not to be taken into consideration. Ceramically speaking, two pieces of pottery ware are identical, whatever may be their differences of form when they have the same body, the same glaze, and the same degree of firing. One is, however, induced to take account of these external differences when he is brought face to face with a very numerous category of similar pieces of pottery of most diverse uses and manufacture.

The differences in chemical composition, which can only be exactly revealed by analysis, are more difficult to observe; they should only therefore be allowed to be taken into consideration for those classes of pottery in which they have a preponderating influence. Finally, the differences in processes of manufacture which are not revealed by the physical properties or chemical composition can only be noted by name among other divergencies, for it is impossible to control them.

**4. First Attempts at Classification.**—Among the ancients, and up to the middle of the eighteenth century, it was not the external appearances and place of origin, presumed or real, which served for classification, because, properly speaking, there was no classification, but only naming of pottery ware.

This method was sufficient so long as ceramic industries remained strictly localised, and limited to the manufacture of a small number of different goods. It became manifestly inadequate from the day that Chinese porcelain caused a stir in European ceramic arts, and from the time when attempts made to imitate this ware produced new kinds of pottery ware.

The result was an inextricable confusion, enhanced by the

tendency that manufacturers evinced, arising from an interest easy to understand, of calling their productions, whatever their nature, by the name of the pottery in fashion. It is for this reason that the most authentic writers of the seventeenth and eighteenth centuries constantly confuse the terms Faience and Porcelain. It is also at this period that we find the expressions appearing "opaque porcelain," "iron stone," and others similar, as substitutes for the term "earthenware," which had then fallen into discredit, and has again become the fashion of our time.

Since the progress of chemistry has enabled the methodical analysis of bodies and glazes to take the place of empirical formulæ, the establishment of a classification based solely on chemical composition has been attempted. The great mistake of this method was the not taking into account the physical properties, or the absolutely preponderating influence of firing.

**5. Classification of Brongniart.**—It was not until 1844 that Brongniart, in his masterly *Treatise on the Ceramic Art*, gave the first rational classification, which has been universally adopted as far as its principal divisions are concerned.

Brongniart divides all pottery into two classes: that which has a soft body, and that which has a hard body, according as this body is capable of being scratched or not by iron. The second group is at once sub-divided into two classes, according as the body is opaque or transparent. By this means we obtain three large classes:—

(1) Pottery ware of a soft body.

(2) Pottery ware of a hard, opaque body.

(3) Pottery ware of a hard, transparent body.

These three divisions are again divided into nine orders, according to the chemical composition of the glaze.

The following Table, containing Brongniart's observations, summarises this classification:—

## Brongniart's Table of the Classification of Pottery Ware.

| Classes. | Names and Characteristics. | Orders. | Names and Characteristics. |
|---|---|---|---|
| 1st class. | Pottery of soft body: that is to say, can be scratched by iron, sandy-clayey, calcareous (generally fusible at china heat). | 1st order. | Fired clay: sandy-clayey body, matt surface, without any glaze. Sub-divisions:— (*a*) Plastic ware (moulded). (*b*) Utensils, bricks, furnaces (moulded). (*c*) Matt ware, jars, urns (turned). |
| | | 2nd order. | Lustred ware: slightly glazed, silico-alkaline. |
| | | 3rd order. | Glazed ware: lead glaze. |
| | | 4th order. | Enamelled pottery: common earthenware, stanniferous glaze, appendices, quarries, bricks, etc., with vitreous glaze. |
| 2nd class. | Pottery of hard opaque body: that is to say, not able to be scratched by steel, silicious, infusible, clayey. | 5th order. | Fine earthenware: colourless body, vitro-plumbiferous glaze. |
| | | 6th order. | Ceramic stone ware: coloured body, without glaze or silico-alkaline glaze. |
| 3rd class. | Pottery of hard transparent body: sandy-clay, alkaline, can be softened. | 7th order. | Hard china: kaolin body, feldspar glaze. |
| | | 8th order. | Natural soft china: clayey, phosphatic, kaolinic, vitro-plumbiferous boracic glaze. |
| | | 9th order. | Artificial soft china: marno-saline body, fritted vitro-plumbiferous glaze. |

Many objections have been made to this classification. The chief one refers to the division of earthenware into two distinct classes, which Deck, the famous authority on earthenware, and an old director of the manufactory at Sèvres, has criticised in the following terms in his work on *Earthenware*:—

"Ch. Brongniart, who for nearly half a century directed the works at Sèvres, divided pottery into two large classes:—

1. Soft bodies;
2. Hard bodies.

In the first class he includes enamelled pottery, called also 'common faience,' tin-enamelled earthenware. In the second class he includes fine pottery, pipe clay, flint ware. I regret I am unable to accept the terms of the clever chemist with reference to earthenware. The expression 'common faience'

conveys the idea of inferior quality, and the expression 'fine faience' implies a kind of distinction. But in my opinion the inferiority or distinction of a piece of pottery does not belong to the greater or less hardness and whiteness of the body, and I cannot bring myself to call the productions of Rouen and Urbino 'common faience'. The word 'faience' is an anachronism as every one knows, since the Persians made faience long before the manufacturers of Faenza. . . .

"For want of another distinguishing word I define 'faience' as any pottery having an earthy fracture covered with enamel."

Among earthenware manufacturers of decorative earthenware the glazing is the chief element for a piece of pottery. The body is only a support, the defects of which are concealed, if necessary, by the use of slip, or opaque enamel. This kind of pottery has not, therefore, the high importance which Brongniart assigns to it.

According to another set of ideas the hardness of the body is no longer so distinguishing a characteristic as Brongniart supposed at the time when he made his classification.

Fired bodies are manufactured which cannot be scratched by iron, *e.g.*, certain vitrified bricks and quarries.

On the other hand, it can be seen that there are some kinds of earthenware, the body of which, although fine according to the sense in which Brongniart would use the term, is yet relatively soft.

It may also be observed that Brongniart, from a purpose perhaps a little archæological, has bestowed too much importance on lustred and soft-glazed pottery. Of these two kinds of pottery the first has not been manufactured for a number of centuries, and the second class has a tendency to disappear.

Finally Brongniart was more especially a manufacturer of china, and has only given a classification which is too rudimentary for so extensive a class of fired bodies. This observation, moreover, will apply equally to nearly all the other classifications.

**6. Various Classifications.**—Salvetat, principal at the chemical works of the factory of Sèvres, proposed, about 1857, to make a classification in which pottery should be divided from the

outset into two great classes: simple pottery (without glaze) and compound pottery (body and glaze). Each of these classes is sub-divided:—

1st class. Opaque mass:—
- 1st sub-division . . . Soft mass.
- 2nd sub-division . . . Semi-hard mass.

2nd class. Hard transparent mass.

The divisions and sub-divisions are then themselves sub-divided, taking into account the composition of the body, then that of the glaze.

This classification, which attempted to force all kinds of pottery into rigorous and symmetrical cases, is certainly the most extensive and the most dogmatic, but at the same time the least practicable and the least natural. For the rest, the primitive classification into simple and compound pottery is arbitrary and impossible to justify.

In Germany Knapp's classification has been pretty frequently adopted. It can be summarised as follows:—

I. *Solid (Dense) Pottery.*

A. China:—
1. With glaze.
2. Without glaze.

B. Stoneware:—
1. With glaze.
2. Without glaze.

II. *Porous Pottery.*

A. Earthenware:—
1. Fine, with transparent glaze.
2. Common, with opaque glaze.

B. Ordinary pottery ware.

C. Bricks, tiles, refractory wares.

In this classification the importance of the glazes is equally exaggerated. Moreover, a piece of earthenware "fine" has not of necessity a transparent glaze, nor common earthenware an opaque glaze.

The following classification proposed by Kolbe is based on the raw material of the body, then on the examination of the surface of the pottery:—

### I. *Clayey Pottery.*

A. Soft body:—
1. Matt surface (fired bodies).
2. Lustred surface (ancient pottery).
3. Vitreous transparent surface (fine earthenware).
4. Enamelled opaque surface (common earthenware).

B. Hard body:—
5. Matt surface (stoneware).
6. Glossed surface (stoneware, salt glazed).
7. Enamelled (fine stoneware).

### II. *Kaolin (or Porcelain Clay) Pottery.*

A. Soft body:—
8. Artificially soft china.
9. Naturally soft china.

B. Hard body:—
10. Hard china.
11. Unglazed china (Parian).

The primary distinction of this classification between clayey and kaolin bodies is not very practical, as it is not of necessity revealed by the physical properties of the body, nor by its chemical composition. Besides, the body of some pottery ware is both clayey and kaolinic, and this kind would not find a place in the table. Then there is a possibility of confusion in the value attached to the words "soft" and "hard," which for clayey pottery denote the physical hardness of the body, and for kaolinic pottery are concerned with its degree of resistance to the action of heat.

Bruno Kerl, in his work on *Ceramic Industries*, adopts a classification which is derived from those of Brongniart and Knapp:—

### I. *Porous Pottery.*

1. Bricks, tiles, various building materials.
2. Refractory ware.
3. Artistic pottery.
4. Common pottery.
5. Ordinary earthenware.
6. Fine earthenware.
7. Pipes.

### II. *Impermeable Pottery.*

1. Stoneware.
   (*a*) Ordinary.
   (*b*) Fine.
2. China.
   (*a*) Hard.
   (*b*) Naturally soft.
   (*c*) Artificially soft.

On the whole this classification is excellent. It can, however, be found fault with for making a distinction between artistic and common pottery, which is very difficult to determine, and for creating an exclusive class for "pipes," while it does not assign any place to "Parian".

**7. Division into Two Classes: Permeable and Impermeable Pottery.**—From the preceding classifications it can be seen that ceramists have been fairly unanimous in dividing ceramic ware into two large classes, but that considerable difference has been manifested in the determination of the distinctive characteristics. Brongniart, Salvetat and Kolbe attribute primary importance to hardness; Knapp and Bruno Kerl to porosity. As it has been already observed, hardness has no longer the absolute characteristic which a certain period was able to bestow on it. All bodies cease from being able to be scratched when they have been fired to a sufficiently high temperature, although this temperature varies for each of them. Porosity, on the contrary, is clearly a distinctive characteristic, and is now admitted so by all ceramists.

Pottery, then, is divisible into permeable and impermeable wares, this qualification naturally being only applicable to the body and not to the glaze, which is always impermeable. The permeability can be observed and even measured by plunging the body into water, and noting the weight of water absorbed at the end of a given time. The methods by which this trial is made, as well as the limits within which the permeability can vary, will be dealt with later on. It will be sufficient to indicate at the present that permeable pottery absorbs a certain quantity of water, while impermeable pottery absorbs only very little or none.

To this primary characteristic of permeability others must be added, which, though less easy to observe and less absolute, serve to distinguish the two classes of pottery.

Permeable pottery showing an earthy fracture, rough to the tongue, is generally soft, and rarely cannot be scratched by steel.

Impermeable pottery is compact, of vitreous fracture, smooth to the tongue, and cannot be scratched by steel.

The first belongs to the composition in which pure clay, rendered more or less fusible by the fluxes, plays the part of an agglomerate; the second belongs to the species of glass capable of assimilating in

its mass non-vitrified material. All impermeable pottery begins at a degree of low firing by being permeable pottery; it only becomes impermeable at a temperature which causes the softness and vitrifaction of its mass. If, on the other hand, porous pottery is heated to a more or less high temperature, or till it becomes impermeable pottery, or, indeed, which is generally the case, till it loses its form, it is then transformed into a vitreous slag.

**8. Division into Five Classes: Terra Cottas, Refractory Fired Bodies, Earthenware, Stoneware, China.**—Permeable pottery is divided into three classes:—

I. Terra cottas.
II. Refractory fired bodies.
III. Earthenware.

Terra cottas comprise all ceramic productions permeable, not covered with glaze, the body of which cannot be heated to a temperature higher than that of firing hard porcelain (1,375° C.) without losing its form or becoming vitrified.

Usually they are rather soft; some among them, however, cannot be scratched by iron, or even sometimes by steel. Their colouring varies usually from light yellow to red and reddish-brown; more rarely they are grey or black, and, in some exceptional cases, white.

Refractory terra cottas are always matt, but can be raised to the temperature at which hard porcelain is fired without losing their shape or beginning to vitrify. They can always be scratched by steel, almost always by iron. Their colouring varies from yellowish or brownish-white to yellow or light grey; in exceptional cases they are black.

Earthenware comprises all permeable pottery with a coating of glaze. Their body is soft or hard, white or coloured in yellow or red.

The fusibility of the body, as well as the presence or absence of glaze, serve to distinguish these three kinds of pottery.

This classification is not now accepted by all ceramists, especially by those who, from respect for tradition, have preserved the divisions proposed by Brongniart. At this stage it would be premature to give our reasons for deciding to adopt it. We will develop these in the second part of this work.

Impermeable pottery is divided into two classes:—

IV. Stoneware.

V. China.

Stoneware is pottery of coloured opaque body, although sometimes only slightly yellowish, greyish or bluish. It is matt or covered with a glaze.

China is transparent, of white body, matt, or with glaze. The body is sometimes coloured, but only for decorative purposes.

The distinction between these two classes lies in the transparency of the body. This is fairly clear, and, as a rule, does not allow of any doubt. The possibility of confusion only arises in the cases of certain fired bodies, when almost vitrified, which can resemble stoneware, and of certain kinds of earthenware of hard, slightly transparent body, which could be ranked with china. The measure of the porosity of the body will in both cases decide the class to which these kinds of pottery belong.

In comparing the five branches of pottery which have just been enumerated with the nine branches of Brongniart's classification, we can establish the following table:—

| | |
|---|---|
| I. Terra cottas . . . | 1. Terra cottas.<br>2. Smeared pottery ware. |
| II. Fired refractory bodies. | |
| III. Earthenware . . . | 3. Glazed pottery.<br>4. Enamelled pottery.<br>5. Fine earthenware. |
| IV. Stoneware . . . | 6. Ceramic stoneware. |
| V. China . . . . | 7. Hard china.<br>8. Naturally soft china.<br>9. Artificially soft china. |

Each of these five classes comprises a certain number of branches of pottery, the description and differentiation of which will be found at the beginning of each of the five corresponding chapters in the second part of this work. This more detailed classification can only be explained after the study of the principles and general processes of manufacture and decoration of ceramic ware.

## II. Brief History of Ceramics.

**9. Origin of Pottery.**—It is in Egypt, the seat of the first known civilisation, that we find pottery ware claiming the greatest antiquity. By making useof the fairly plastic deposits of the overflow

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of the Nile, the Egyptians first manufactured bricks of rough earth; they fired them as soon as chance led them to discern the property clay possessed of hardening under the influence of heat. In some borings made by Linant Bey, debris of bricks of fired body were found at a depth of twenty-five to thirty feet below the actual level of the valley of the Nile, which fact, taking into account the progressive elevation of the soil from the overflows, would lead us to suppose that the beds containing those fired bricks were deposited 10,000 years before our era. According to Mariette Bey, there are found in the tombs of the Memphite period (B.C. 5000-3000) vases of terra cotta which were intended to contain provisions for the deceased. Also, on the walls of the tombs of the Beni-Hassan, pictures have been discovered pourtraying scenes from the life of Egyptian potters, modelling vases and firing them in an oven, at a time corresponding to the Theban period (B.C. 3000-1700). It is also to this period that we attribute the discovery of glazes and the manufacture of the first pieces of earthenware found in the pyramid of Saggarah. During all the period following (B.C. 1700-500) the art of earthenware acquired a rare perfection, as can be proved by numerous small figures in blue or green and the decorations of the temple of Tell-el-Yadouai built by Rameses III.

Whether the Chaldeans and Assyrians had borrowed their processes from the Egyptians, or whether they themselves had discovered these, it is known that after having for a long time used crude bricks in their buildings they erected the palaces of Crœsus at Sardis, of Mausolus at Halicarnassus, and of Attalus at Tralles in red fired bricks of a beautiful manufacture. The ruins of Nineveh and Babylon consist of accumulations of bricks low fired, of a yellowish white, sometimes covered with blue, bluish-grey or yellowish-white glazes. Tombs made of a body fired in a single piece, or formed by two pieces cemented together, evince the skill already reached by Chaldean and Assyrian potters at this remote period. But the most curious fired bodies which have come down to us are the clay plaques on which the Chronicles were written, which, after having been fired, were preserved in the libraries. The most ancient one which has been discovered is that of Sargon the Ancient, dating from 3800 years before our era.

It is possible that the Indian races learnt the manufacture of

fired bodies and glazes from the Assyrians and Chaldeans. Of the origin of these old races there is still but very little known; but in the Vedas, their collection of hymns, mention is often made of pottery.

On the other hand, the Persians, successors of the Assyrians, inherited their traditions and carried the manufacture of earthenware to a high degree of perfection, while the Phœnicians, and then the Greeks, neglecting glazes, initiated themselves in Asia Minor in the art of the potter, and manufactured terra cottas, which afterwards had such a pure artistic characteristic. These commercial nations and navigators have, by means of their numerous colonies, been the initiators of the art of fired bodies among all the nations bordering on the Mediterranean, and of those at the north of Europe.

Separated from this first home of civilisation by the deserts and mountains, for a long time insurmountable, the Chinese also discovered the principles of ceramics. According to the Chinese Annals the first pieces of pottery were manufactured by Kouen-Ou, who lived during the reign of the Emperor Hoang-Ti (B.C. 2698-2599). These were doubtless vases in glazed or enamelled earthenware.

At an early date the Chinese used ceramic ware for the construction and decoration of buildings in the shape of bricks or enamelled tiles, but their great discovery, that of impermeable pottery, stoneware and china, is much more recent; the first mention of it is made in a work published under the Emperor Wan-Ti, in the dynasty of Han (B.C. 175-151).

At the time of the discovery of America the natives manufactured remarkable terra cottas, and archæological discoverers have confirmed that in certain districts of Mexico and Central America the origin of this manufacture was of rather remote antiquity, dating probably from more than 1000 years before the Christian era.

From all these facts it would appear that the manufacture of terra cotta, the first halting place in the ceramic art, was invented, at least, by three different peoples—the Egyptians, the Chinese, and the Mexicans—at the beginning of their respective civilisations, that is to say, at periods too remote for us to be able to assign a date.

The art of covering fired bodies with glaze must have been

known to the Egyptians about 4000 years before our era, and it is probable that the Chinese on their part discovered it about 1000 years later. Finally, it was about 200 years B.C. that the latter invented stoneware, then china.

**10. Ancient Terra Cottas.**—The first fired bodies of the Egyptians and Assyrians were made from a clay not very plastic, and difficult to work. To remedy this defect straw or herbs were added to the body intended for bricks and other thick articles. As for statuettes, for inscriptions, a fairly rough outline had to be first made before firing. This method of manufacture does not appear to have been employed outside Egypt and certain parts of Asia Minor. This was in consequence of the geological formation of those vast plains of alluvia in which the fertility of the soil engendered the first civilisations.

In all other countries, on the contrary, the first ceramic productions present a remarkable analogy. Although manufactured at distant centuries by the Phœnicians, Greeks or Romans, Celts, Gauls or Germans, Indians or Malays, Americans or Africans, they present themselves under the form of very porous terra cottas, soft or moderately hard, the colour varying from yellowish or greyish white to orange yellow and grey. The raw material has everywhere been a moderately plastic clay, a little calcareous, more or less ferruginous, which has been formed into the condition of a body, then fired nearly always at a low temperature. Such was the manufacture which existed on the shores of the Mediterranean 4000 years ago, and such it is that we still see used in our time by certain American and South African tribes. Everywhere where man has found this special clay he has been enabled to manufacture these old fired bodies without the aid of any stock of tools, only utilising the heat produced by a clear fire of wood. This extreme simplicity in manufacture has caused terra cotta to be the first article manufactured by man with the assistance of heat.

The first pieces of pottery of the kind manufactured have been vases for containing food or liquid; it is not until later that it has been possible to make thicker ware, bricks or tiles of a more difficult firing. The shapes of these articles in terra cotta have naturally varied a good deal, according to the uses

for which they were intended, and the particular genius of each people. Brongniart in his *Treatise on the Ceramic Art* has devoted several chapters to this subject, which are interesting more from an archæological than from a ceramic point of view, and we would refer those of our readers for whom this question has any interest to these chapters. We must, however, mention the jars or amphora of considerable dimensions manufactured, as Brongniart says, "over all the earth from a remote period, perhaps several centuries before the Christian era. The manufactories of these pieces, which are remarkable on account of their dimensions, being always very large, but sometimes gigantic, are not very numerous, but exist in all countries, in Africa, Asia, America, Italy, Spain, France." These vases range from 5 feet up to 10 feet high, a maximum diameter from 2 feet to 3 feet 3 inches, the thickness of the body varying from $1\frac{1}{4}$ to $2\frac{1}{2}$ inches. They were made for the purpose of containing liquids, chiefly wine, and have since been replaced by wooden vats.

Chiefly among the nations who have manufactured these old terra cottas, which for the most part have been, or are still, the only ceramic productions known, we must mention the Greeks, because of the plastic perfection which they were able to give to their pottery, and next the Romans, who were the creators of the industry of fired wares for the purposes of construction.

Under the name of Greek terra cotta we must not only comprise those which were manufactured actually in Greece, but also the productions of the Archipelago, the Isle of Milo in particular, and other old Greek colonies, of which one, "Greater Greece," really southern Italy, was the country from which originated the kind of pottery called "Campanian" ware, which will always remain the most perfect model of pottery in fired body.

Besides the admirable purity of form, the Greek potters knew how to use fairly fine clays, probably washed and fired at a rather high temperature, which gave to their bodies a special hardness and fineness. After having polished the surfaces before firing, in order to give a kind of brilliance to the fired pottery, they then invented the process of decoration known as "slipping," which consists in putting on to the body ornamentation

made by means of another body of a different colour. Then they began to cover the fired bodies with a kind of glaze, with a lustre, according to the expression sanctioned by Brongniart, which by its strongly alkaline composition determined the vitrifaction of the surface. These lustres were coloured either in red by oxide of iron, or in dark brown by a mixture of that oxide and manganese. The Greek manufacture, which must have originated nearly a thousand years before our era, disappeared completely three or four hundred years after Christ, and remained almost unknown until the beginning of the eighteenth century.

It is impossible to compare Roman pottery, even that called Etruscan ware, with the remarkable productions of Greek art, but, on the other hand, those conquerors of the known world everywhere introduced the use of fired ware into buildings. The large bricks, or rather Roman slabs, as well as their tiles, still remain as numerous monuments. This manufacture, which attained its highest point at the time when the power of the empire was greatest, declined with it, and almost disappeared, though did not entirely cease, during the beginning of the Middle Ages.

When the various European nations began to form themselves, the traditions of the Roman potters were gathered again, little by little, but it is only since the Renaissance that European manufacturers of fired bodies have been able to equal, and then surpass, their masters.

**11. Ancient Earthenware, Persian, Arabian and Moresque.**—We have seen that the Egyptians appear to have been the first people to cover fired bodies with glaze, that is to say, with glass. From the fifteenth century before our era the Egyptians used enamels, with white, blue, or green colourings. The nature of the body being very silicious, hard, almost vitrified, caused it at a certain period to be confused with china, but this is refuted on a close examination: Egyptian enamelled pottery is certainly earthenware.

The Assyrians and Chaldeans also manufactured similar pottery, although with less perfection; but to these nations belongs the great honour of being the precursors of the Persians, who brought the art of earthenware, particularly of monumental

earthenware, to a degree of perfection which has not been equalled till our own day.

Thanks to M. Dieulafoy, the Louvre Museum possesses two beautiful frescoes, which adorned at one time the palaces of the kings of Persia at Susa, manufactured under the reigns of Darius and Artaxerxes Mnemon, that is to say, B.C. 525-362; they would in our own days do honour to the most clever ceramists.

The body employed by the ancient Persians was extremely silicious, having the appearance of a piece of soft stone. The slightness of its plasticity naturally rendered its moulding very difficult. For this reason some authors have expressed their opinion that the bricks which serve as a support for the glaze are blocks of natural stone which have been carved and sculptured. Ceramists have not adopted this opinion. They rather think that these bricks are formed of a mass of sand together with a little clay. As for the ornamentation, like numerous inscriptions, they need not have been moulded, but may have been sculptured by hand, either on the rough or fired body. The glazes are very alkaline, possessing much brilliance, with white, yellow, or blue colourings. At a later period the Persians used more plastic bodies, from which they were enabled to make vases and dishes.

Whereas the Roman Conquest destroyed the art of faience in Egypt, the Persians maintained its traditions, and must have been in full possession of this manufacture, which they knew how to bring to such a high degree of perfection, before they were conquered by the Arabs in the seventh century.

For the long period of nearly a thousand years, during which the Persian art must have reached its highest point, the history of ceramics is at a standstill. Arabian civilisation so engrossed its conquered peoples that for centuries Persian faience was unknown; and it is not until our own time that the discoveries of archæology have brought to light the splendid witnesses of that bygone civilisation.

It is one of the most curious problems of history to seek out the causes which prevented the Greeks and Romans, whose intercourse with the Persians was so frequent, borrowing the magnificent art of enamelling from them. It has been said that the Greek

predilection for purity and delicacy of form caused that people to dislike an enamel which would clothe an object with any pasty substance; but this resentment could scarcely apply to the Romans, who, on the contrary, were very prone to adopt the usages of the nations whom they conquered. Whatever may be the reasons for refraining from its adoption, it can only be regretted, for this has been of the greatest detriment to the development of ceramics.

The art of faience was only introduced into Europe by the Arabs and Moors after it had been ignored by all the classic antiquity and the Middle Ages, that is to say, for more than 1500 years.

It is difficult to follow the history of ceramics for the first centuries of the Arabian Empire, the documents being missing or obscure, but it is certain that the manufacture of faience continued in Persia, then spread over Syria, Egypt and Spain. It was only towards the eleventh century, when the Arabs were superseded by the Moors, that a new kind of manufacture appeared in Spain, which was distinguished from the Persian wares chiefly by the metallic lustre of the glaze. The manufacture of the celebrated Hispano-Moresque faience became concentrated in the island of Majorca, at Malaga, and at Manises, near Valence. The latter consists of wall tilings, dishes and vases, frequently having great purity of form. Darcel says: "The decoration consists of Cyprus ornamentation, of animals inserted in medallions, which adapt themselves to the contours of these pieces, and of interlacings painted in blue, of large stars with rays overlapping, imitating the ceiling of the Alhambra, and of boughs with long-leaved foliage painted in pale yellow. Inscriptions in Arabian characters, which are easily transformed into ornamentation, frequently occupy an important place in the decoration. The ground is of white enamel, which adopts a slightly pinkish tint owing to the evaporations of the metallic colour." The celebrated vases which adorn the Alhambra at Granada, and are considered masterpieces of Moorish ceramic art, were probably manufactured at Malaga about 1320.

At a later period the decoration came under the Christianising influence of Spain and Italy. Rosettes, shields, armorial decorations, and religious emblems now often replaced the Moorish designs. At the beginning of the sixteenth century this style

of manufacture was at its height, if not from an artistic standpoint, at least from the importance of the output.

However, the conquest of Spain by the Christians struck a fatal blow to this fine industry, for in spite of the protection afforded it by kings, it declined rapidly and disappeared entirely from the localities it had rendered famous. The honour of inheriting this glorious art fell upon Italy.

Persian art also had a short period of brilliance at Damascus, and in the island of Rhodes. The manufacture consisted of dishes, vases, cups and basins, in which floral decorations of roses, tulips, hyacinths, carnations of a bright red played the chief part. These pieces of faience were made in the island of Rhodes, under the sway of the Order of Jerusalem, from 1320 to 1523, at the time of the conquest of the island by Soliman II. As for the productions of Damascus, their history is almost unknown. They seem to have disappeared in the course of the seventeenth century.

Lastly we must mention the faience ware of a distinctly Arabian characteristic, which was made in Sicily during the fourteenth and fifteenth centuries, which has been termed Siculi-Arabian. It disappeared at the time of the advent of stanniferous faience.

**12. Italian Faience Works.**—Up to the fifteenth century the only glaze known was the plumbiferous glaze. Having been used from the year 1100 at Pesaro, it was employed for the coating of tiles, vases, more or less ornamented with incrustations or painted with metallic oxides. Its transparency allowed the yellowish but more often red colouring of the body to be seen. The origin of the use of plumbiferous glaze is unknown, but it is generally admitted that the tradition of this glaze, known to the Egyptians, Greeks and Romans, though little used by them, was handed down to the thirteenth century, when it was rescued from oblivion and became generally employed.

From the eleventh century the potteries of Italy were the most renowned in Europe. The intercourse which the Italians had with the East gave them a knowledge of Arabian faience and their metallic lustres, which they strove to equal. For many centuries they were content to be imitators, but in 1440, Luca della Robbia, a native of Florence, made use of stanniferous opaque enamels for the production of a new kind of faience, which, for three centuries,

held the chief place in ceramic art. Della Robbia was a sculptor, and his object in covering fired bodies with enamel was to render them imperishable. The principal works of his extant are statues, or groups covered with enamels of a uniform colour, chiefly white and blue, sometimes green, rarely brown or yellow. The great discretion used in his colours, the purity of style shown in his shapes, marks his work with a peculiar characteristic of serenity which is not found among his successors. At his death Luca was succeeded by his nephew, Andrea, who had seven sons, five of whom became distinguished ceramists in their time. They produced bas-reliefs, friezes, statues, medallions, altar pieces, remarkable for the perfection of technical processes displayed. "The enamel on them," says M. Garnier, "is very smooth, very pure and without any cracks; the clay is well fired, and the shrinking has been so cleverly calculated that all parts which compose the whole of the bas-reliefs and statues of large dimensions are adjusted and placed together without leaving any gap."

At the end of the fifteenth century the manufacture of a new stanniferous faience developed considerably throughout the whole of Italy. This was known by the name of "majolica" a corruption of the name of the island of Majorca. This designation has been the cause of much discussion as to whether the Italians received their inspiration from the Moors of Spain or the Arabs of the East. It seems probable that they came under the influence of both. The Italian manufactories were very numerous, and we can only take notice of the chief among them.

Faenza, in The Marches, which has given its name to the French word "faience," from 1487 manufactured wall tiles; later it became known for its blue decorations on a blue enamel of another shade (berettino), and the presence of red tints in the painting.

Urbino, in the duchy of that name, reached the highest pinnacle of its fame in the second quarter of the sixteenth century, owing to the protection of the Duke Guido Ubaldo II. Many ceramists, whose names are worthy to be preserved, have rendered this manufactory famous: Guido Durantino and Francesco da Rovigo before 1545, Orazio Fontana at the end of the sixteenth century, Antonio Patanazzi at the beginning of the seventeenth. At Urbino, reproductions of the pictures of Italian masters, and particularly of

Raphael, were first started. Here also were manufactured grotesque pieces, ornaments in relief, salt cellars, inkstands and especially vases fashioned by Battista Franco, and executed by Orazio Fontana, which are considered the masterpieces of this factory.

Pesaro, in the same duchy of Urbino, has been more famous for its vessels and metallic lustres. The most illustrious artist of this city was Gironimo Vasaro. The manufacture ceased at the beginning of the sixteenth century.

Gubbio, also not far from Urbino, is only known for the name of a ceramic artist, Georgio Andreoli, who died in 1540, to whom a few pieces with metallic lustres of ruby red are attributed. Of all the localities of the duchy of Urbino, Castel-Durante has had the most active manufacture, if not the most artistic. It only ceased at the beginning of the eighteenth century. Its faience ware was distinguished by a large and bold design, a brownish colour, generally with blue or yellow grounds.

Then we may mention Caffaggiolo in Tuscany, the productions of which bear a close analogy to these of Faenza, Deruta in the Papal States, famous for its metallic lustres of chamois yellow, Ferrara, Venice, Padua, Verona, Savona, and lastly, Castelli in Abruzzo.

Deck says: "Italian decorators practised their art on all the shapes produced in ceramic ware, floor and wall tiles, plates, dishes, bottles, basins, gourds, apothecaries' vases, decorative vases, cups, inkstands, fonts, etc. They had all kinds of decorations, simple ornamentation, arabesque and grotesque, trophies, scenes from history, mythology and landscapes." Italian ceramists raised themselves to the highest degree of their art, and evinced a professional skill of a high kind in extracting from the materials they employed their fullest worth. This beautiful manufacture, after having reached its culminating point in the middle of the sixteenth century, then declined rapidly, and disappeared almost entirely at the beginning of the seventeenth century.

**13. French Faience.**—The use of plumbiferous glaze seems to have spread in France during the course of the twelfth century. It was used first of all to cover bricks and paving tiles, later

it was also used in the manufacture of vases of various shapes. From 1225 a factory of this kind existed at Troyes, another at Pontaillier, near Dijon, and later at Paris and Saintes. But it was most used at Beauvais, and in the neighbouring localities of Savignies and La Chapelle-aux-Pots. The pottery productions of Beauvais were covered with a green or jasper glaze. From the sixteenth century, however, glazed pottery ware lost its artistic characteristic, and was only employed for domestic wares. For this purpose the use of glaze has continued till our own day, but this has a tendency to disappear.

At the beginning of the sixteenth century Italian ceramists began to be invited to France by Francis I., and by great nobles, such as Montmorency. The decoration of the castle of Madrid, near Paris, is due to Girolomo della Robbia. Afterwards they founded factories at Lyons, at Nantes, at Le Croisic, but these only had an ephemeral existence, and soon fell victims to the caprices of fashion, and to the strife waged against them by French ceramists.

The first pieces of faience of purely French origin are those named after Oiron, which, for a long time, remained an enigma in ceramics. They were remarkable for the white ivory tint of their very hard body, the lightness and finish of their decoration, while their forms resembled those of the goldsmiths' productions. For a long time their place of origin and date of manufacture were unknown. Recent researches have brought to light that these pottery productions, which for long were described as "Henri Deux" faience, because this king possessed some of its pieces, were manufactured, not at Oiron, but at Saint-Porchaire, in Deux-Sèvres, from 1529 to 1568. This remarkable manufacture died out without leaving any trace, and without exercising any influence on the development of French ceramics.

Bernard Palissy, born in 1510 at Chapelle-Biron, near Agen, after having followed various trades and travelled in France, Germany and Flanders, settled about 1542 at Saintes (Charente-Inférieure), and there discovered the composition of white enamel, doubtless of Italian origin, patterns of which had come into his possession some years previously. By means of experiments, which were frequently impeded by poverty, he succeeded in producing faience of an original character, which attracted the

attention of many great nobles, and particularly that of the High Constable de Montmorency. After many years devoted to ceramic work, having adopted the reformed religion, he was imprisoned at Bordeaux in 1562. By the intervention of the High Constable de Montmorency he was soon released, and then established himself at La Rochelle, and afterwards at Paris, where he enjoyed the protection of Catherine de Medici. He was again arrested for his opinions in 1588, after the death of his protectors, and died in prison at the age of eighty.

"Besides wall tiles, Palissy also produced stove tiles, a beautiful example of which can be seen in the old collection of the Comte de Pourtalès, vases decorated in various styles, ewers, vases, cups, salt cellars, ink pots, candlesticks, and even statuettes; but his most remarkable works are his 'rustic figulines,' as he called them. These were dishes with ornamentations of fishes, serpents, frogs, cray-fish, lizards, shells and plants. These were not made for use, but were designed as show pieces for the sideboards which were at that time greatly in fashion."[1]

Besides being a ceramist, Palissy was also a naturalist, geologist, and writer. "He possessed," says Brongniart, "the qualities which make a hero: a high aim, a perseverance to the end, which could overcome without drawing back or stopping for a moment before any obstacles which confronted him, final success, and the consequent acquisition of popular favour." But at the same time he was wrong in keeping to himself the secret of his remarkable works. "Thus the art which he had so painfully learnt disappeared almost entirely with him, his immediate successors producing only works of mediocrity, relatively, dull, without any ingenuity, and made from old moulds."[2] His most remarkable works, the property of a few great nobles, remained almost unknown until the beginning of our century. He might have been unquestionably the master of French ceramics, whereas he was only a brilliant apparition idealised by popular tradition.

It was not until 1602 that the Conrade Brothers, who were born at Albissala, near Savona, were invited to France by Louis de Gonzague, and began to manufacture faience at Nevers, following the processes which they had learnt to make use of in Italy. This

[1] Blondel. [2] Garnier.

manufacture achieved a great success, and in 1644 a son of one of the founders was appointed "gentilhomme servant et fayencier du Roy."[1] The family of the Conrades died out in 1677. Other factories, however, were established at Nevers; in the year 1632 there were four of these, the most important being directed by the Custade family. Up to 1660 the pottery wares of Nevers were merely imitations of Italian faience; later, oriental pottery was manufactured. The productions of this period, says M. Garnier, "are remarkable for their free and ingenious execution, and especially for the beautiful blue often accompanied by manganese." The output became considerable, but the manufactures more and more common. "Statuary, not usually deserving much commendation, was turned out from the workshops at Nevers; then the factory at Rouen towards the end of the seventeenth century, and that of Moustiers at the beginning of the eighteenth century, founded a decorative art which attracted favour and orders. Nevers began to imitate the productions of Moustiers and Rouen without ever succeeding in obtaining the red which the manufactories of this latter town produced on their ware in the eighteenth century. Then the wares of Saxony were imitated, until at length the factories of Nevers, having reached the last degree of decadence, by the end of the eighteenth century produced nothing but common ware illuminated with Republican emblems" (Darcel).

In 1673 the first manufactory of faience was established at Rouen by Louis Poterat, who, having come under the influence of Nevers and Delft, could yet free himself from every kind of imitation and created the Rouen style, which takes first rank among French faience, and by many is preferred to the most beautiful productions of Urbino.

"These are designs without relief, symmetrical, forming cartouches, scallops, which, being distributed symmetrically over the surface of the pieces, radiate round the centre if it is a dish or plate, but, in the case of vases, descend from the edge and spread over the centre. This kind of decoration is usually in blue on enamel white, but yellow, green and red are met with on these pieces" (Darcel). "In 1786," says Deck, "Rouen had eighteen faience factories; at the end of the century there were scarcely

[1] Gentleman-in-waiting and financier to the King.

any. English competition had, by its cheapness, triumphed nearly everywhere in the manufacture of table ware. Rouen exercised a considerable influence on a great number of French and foreign factories of faience, and rightly so. No other ceramic centre in France has been able, to the same extent as Rouen, to prove the vitality of the sentiment of decoration in our country."

The Moustiers factory of faience was founded about 1680 in a small town of the Basses-Alpes by the family of Clérissy. In 1789 there were a dozen faience factories, but these disappeared during the Revolution. M. Garnier says: "The manufacturers of faience at Moustiers knew how to produce an original decoration very singular in style, and it might almost be said—if this did not appear too ambitious a statement when applied to simple ceramic productions—that they founded a kind of school, whose influence was felt in every factory from the south of France to Spain."

The Hannong family, who were very eminent ceramists, founded at Strassburg, in 1709, a factory which remained until about 1790. Contrary to preceding manufacturers, the Hannongs, following the processes used for porcelain, painted their decoration on the fired enamel and not on the raw enamel. M. Garnier says: "The faience wares of Strassburg, which are distinguished by the beauty and purity of their enamel, by their elegant and fantastic forms, and especially by the vivacity and freedom of their colours, notably purple and carmine, do not arise in any way from what had been previously manufactured".

To these four great centres of French faience ware—Nevers, Rouen, Moustiers and Strassburg—each of which had its peculiar characteristic, we must add a great number of other manufactories which are more or less connected with them. To cite the best known, Marseilles, Montpellier, Bordeaux, Lunéville, Niderviller, Saint-Amand, Sceaux, Lille, Epinal, etc.

M. Garnier says: "At the end of the eighteenth century the manufacture of stanniferous enamelled faience, which had attained so much splendour for so long a time, had for many years been in a full decline. Rouen and Moustiers had lost almost all their manufactories which had formerly been their pride and wealth. Nevers, and the secondary factories, only produced for the purposes of commerce heavy faience ware

commonly and roughly painted, and if some towns, such as Strassburg, Niderviller, Sceaux, Marseilles, etc., occasionally manufactured pieces which were delicately executed and decorated with unquestionable talent by genuine artists, it was because, even in their decoration executed at the muffle fire on fired enamel, and occasionally enriched with gold, they imitated porcelain ware, the use of which began to spread among the great houses and among the upper middle class, and which emanated either from the factories recently established at Paris and in many parts of the kingdom, or from the extreme East, whence they were imported into France through the agency of the East India Company. But porcelain, the price of which was relatively high, was not the only cause for the neglect and inferiority into which the manufacture of faience had fallen: a new kind of pottery having its origin in England accounted for this in a great measure."

**14. German, Dutch, and Various Faience.**—Fired bodies with lead enamel developed largely in Germany during the close of the Middle Ages. People were not content only to manufacture movable goods, they also produced architectural pieces. Nuremberg was already celebrated for its pottery ware, when in 1503, Hirschvogel, who was sent on a mission to Italy, there learnt the secrets of the manufacture of majolica.

M. Garnier says: "It is chiefly to Augustine Hirschvogel that we generally attribute those vases which are at the present day so rare and choice in Germany, being covered with many-coloured enamels, which are fairly pure and very harmonious, and having figures in relief round the centre, or in the cavities in the form of niches made in the body of the vase. But above all the fame of the manufactures of Nuremberg rested on those magnificent stoves of clay covered over with a beautiful dark green or brown glaze, enriched with gilding, consisting of two cubic masses placed one above the other, and formed by pieces made separately, tiles, plaques, pilasters, caryatides, capitals, etc., the union of which constituted a rich and varied harmony. On the surface were reproduced in relief, mythological subjects, scenes taken from the Old and New Testaments, allegorical figures, and decorative subjects."

In the eighteenth century Nuremberg also manufactured dinner ware, or show pieces usually decorated with loose bouquets; but the finest grates date from the sixteenth century; by the eighteenth century this manufacture had fallen into decay.

Among other German factories of faience, we can only mention Ansbach (Bavaria), which made fairly good imitations of the productions of Rouen; Höchst on the Main (1720-1794), the decoration of which resembles that of porcelain; Frankenthal, which imitated the wares of Strassburg; and Bayreuth, which made pieces of services and vases generally with blue decoration.

Towards 1584 there was founded in the Netherlands an earthenware manufactory, which, after difficult beginnings, became by the end of the seventeenth century of considerable importance, both for its output and the artistic value of the ware. Under the strict supervision of a powerful corporation, the Guild of St. Luke, the Delft productions rendered the name of that town famous. During the time that this factory lasted—more than two centuries—759 "faienciers" were enrolled on the registers of the corporation. At first favoured by the important development of Dutch commerce in the seventeenth and eighteenth centuries, the factories of Delft experienced later the same fate as the French factories, and disappeared about 1800. Among the numerous ceramists who contributed to the fortune of Delft we must mention Herman, Adrian and Gerrit Pietersz, Albrecht De Keyzer, Abraham De Kooge, Frederick van Frytom, Van Eenhoorn and Augustijn Reygens. Delft manufactures are divided into three periods. In the first the decoration, of an ordinary character, is in camaieu blue with dark traces inclining to a violet brown, showing compositions of several parts. The second is characterised by a notable improvement of the same process, and by a remarkable imitation of Japanese porcelain. Finally in the third period, which dates from the end of the seventeenth century, the manufacture became principally commercial, and a multitude of goods were produced, of the most varied kinds, and some perfect imitations of porcelain ware from China, Japan and Saxony.

Other countries also, especially in the eighteenth century, possessed factories of stanniferous ware. Among these may be

mentioned that of Talavera in Spain, which gave its name to stanniferous faience in its native country; and those, of less importance, of Alcora and Seville. In Switzerland the factory at Zürich was celebrated chiefly for its stoves in the eighteenth century, and that of Thun for its decoration by means of drops of various coloured glazes. In Sweden the crockery ware of Rörstrand imitated Marseilles and Strassburg in the matter of decoration, and likewise the porcelain ware of Saxony; that of Marienborg was influenced in its decoration by Strassburg. Finally we may also mention the factories of Bruges and Liège in Belgium.

**15. English Faience.**—The manufacture of lead glazed pottery ware, as well as at a later date that of enamelled ware, seems to have been very little developed in England. Faience ware was imported from Delft, which name was employed to designate all stanniferous pottery. We can only mention the factory at Lambeth, on the outskirts of London, founded by the Dutch, and those of Burslem in Staffordshire.

Such was the condition of affairs when, in 1770, Astbury, the son of a Burslem potter, noted by chance the whiteness of silica powder used by a veterinary surgeon, and it occurred to Astbury to mix this powder with the faience body. The success produced realised his hopes, the body became whiter, was remarkably hard, and lent itself to all kinds of decoration.

Numerous manufactories making use of this discovery were established at Burslem, Hanley, Newport, Leeds, Liverpool, Fulham and Lambeth. Of these, that of Leeds was the most celebrated, and it was not long before its productions were sent all over Europe. However, the ware made was generally of a common kind, but was brought to a high degree of perfection by Josiah Wedgwood, the most celebrated English ceramist.

Wedgwood was born in 1730 at Burslem, and was a son of a potter in this town. After having had several partners he founded, in 1759, a factory in his native town, where he manufactured pottery of a cream-coloured body. This achieved a considerable success, and being patronised by Queen Charlotte, became known as Queen's ware. Afterwards associating himself with Thomas Bentley he devoted his time to the imitation of antique art, and manufactured vases, cameos, medallions, the

execution of which was as remarkable as it was careful. Wedgwood died in 1795, after having established important works, acquired an immense fortune, and leaving behind him the memory of a man of noble and charitable character.

The wares produced by Wedgwood are classified, according to Mr. Church, as follows: Cream faience for dinner ware, painted in colour, or printed in black or red, rarely enriched with gold; black pottery ware in the form of vases, medallions, busts, services of various coloured and gilt decoration; red pottery ware for imitating cameos; fine faience of a white body; marbled pottery imitating marble, granite, agate (stoneware); and finally decorated pieces with light relief on a greyish-blue ground in the form of vases, candlesticks, small boxes, snuff-boxes, buttons, and especially bas-relief imitations of the antique, from models by the sculptor Flaxman.

By the end of the eighteenth century the manufacture of the new kind of faience had developed considerably: it supplanted stanniferous faience, which had already been put in the shade by porcelain. At the beginning of the century it ruled supreme, and all countries of Europe paid tribute to the faience manufactures of Staffordshire.

**16. Stoneware.**—The history of the manufacture of stoneware is much shorter and less eventful than that of faience. It has been seen that this kind of pottery was known to the Chinese many centuries before our era. Certain Egyptian pottery ware can also be included in this category, besides which a few specimens of glazed pieces of pottery ware exist which were manufactured during the Middle Ages. In fact, we know that certain fired bodies are transformed into stoneware as soon as the temperature of their firing is sufficiently high; in this case an incident of firing is enough to produce stoneware. However, we do not find the regular manufacture of this pottery ware in Europe before the fifteenth century. It was probably first carried on at Raeren, an old parish of the duchy of Limburg, in the middle of the fifteenth century. About the same time a similar manufacture existed at Frechen, near Cologne. The wares of both factories were of a yellowish body, covered with a more or less dark brown glaze; these are chiefly vases and jugs, with orna-

mentation in relief representing scenes of hunting, dancing, peasants, and Biblical subjects. We would also mention a stoneware manufactory at Siegburg, opposite Bonn, which produced matt stoneware of a slightly greyish body; but it is at Hoehr and Grentzhausen, near Coblentz, that we find factories whose wares, wrongly known by the name of Flemish stoneware, acquired such a wide reputation. The body is greyish or bluish, decorated with blue, violet, or brown enamels. The ornamentation is rich and the forms generally elegant.

At the end of the seventeenth and the beginning of the eighteenth century there also existed at Creussen, not far from Bayreuth, a manufactory of stoneware of a brown body, with black glaze, and small figures or coats of arms in relief, painted in light colours.

In France the manufacture of stoneware began at the commencement of the sixteenth century, and was carried on at Savignies and La Chapelle-aux-Pots, near Beauvais. These pottery wares, of a greyish or bluish body and a uniform blue glaze, enjoyed a wide reputation in the north of France up till the time when, towards the end of the seventeenth century, the infatuation for faience caused the abandonment of stoneware and so much ornamental pottery; the manufacture was then confined to domestic goods. The Rhenish factories had for more than half a century ceased to manufacture Flemish stoneware, but the traditions of that beautiful manufacture had not disappeared, for we find that, about 1690, the Brothers Elers, of Nuremberg, established themselves at Bradwell, in England, and there founded a factory for stoneware of a red body, then of a yellowish white, with salt glaze. The reputation of their potteries soon became the means of rival factories being established. Among these we must mention that of Fulham, founded by John Dwight, who, from 1721, manufactured jugs, dishes, goblets of a brown glaze, decorated in relief with hunting subjects and grotesque figures.

Towards the end of the eighteenth century the manufacture of stoneware made considerable progress in England, due in part to the researches of the celebrated ceramist Wedgwood, whereas on the Continent it was neglected. Many manufactories

in Staffordshire produced at the same time faience and stoneware; but we must come to 1819, the time at which Messrs. Doulton established the works at Lambeth, and it is from that date that a new era begins in the manufacture of stoneware.

**17. Oriental Porcelain.**—We have seen that we can trace the manufacture of Chinese porcelain ware back to about 200 years before Christ. At one time some Chinese porcelain, discovered in some Egyptian tombs, was believed to have had a much greater antiquity; but careful investigation has shown the error of this, and confirmed the annals of the Celestial Empire. However, those first pieces of porcelain do not at all resemble the ware which is now so described. A greyish body, thick, very little transparent, the glaze usually crazed, such is the appearance of the porcelain manufactured during the dynasties of Han, Wei-Tsin and Jsoni, that is to say, from B.C. 206 up to A.D. 621.

Under the dynasty of the Ting (621-954), there was a considerable improvement in the manufacture, the body became whiter, the crazing disappeared, and the glaze, though generally of a greyish-green, is sometimes blue. This progress continued under the dynasty of the Thai-Yong-Youen (954-1368); the body becomes fine and transparent, yellow and green colourings are added to the blue. From this period also date the first "flammes," and the famous development of Nanking pottery.

Under the double dynasty of the Ming (1368-1488 and 1488-1643) Chinese pottery ware acquired the qualities which have rendered it so famous. The style of decoration is sober, the colouring pure, and the forms often elegant. Under the Chinthe-Khang-Hu (1643-1662) and the Young-Thing (1662-1736) pink, red and violet colourings were adopted.

Lastly, from the dynasty of the Kieng-Long (1736) Chinese porcelain has maintained the same appearance which we now see. The decoration, composed chiefly of figures, has become more and more exaggerated; the gilding, which was at first used in moderation, has ended by overrunning the whole of the decoration. Chinese ceramists delight in the most extraordinary exhibitions of skill, and art is compelled to give place to the cheap commercial productions which encumber our bazaars. In some works we find the Chinese porcelain ware classified under

various headings: blue, yellow, pink, and even chrysanthemums and peonies. It is scarcely necessary to remark that such a classification has nothing in common with ceramics.

In China the manufacture of porcelain has always been confined, almost exclusively, to the provinces of Kiang-Si, and has been exported from the port of Canton.

If the Japanese annals relegate the origin of Japanese porcelain to the first century B.C., according to Chinese traditions they only began to manufacture it there from the beginning of the seventeenth century, and it is only towards the middle of our century that Japanese art has obtained a certain amount of independence. The body appears to be whiter, more transparent, and the decoration more careful and less heavy in style.

The first pieces of Chinese porcelain which came to Europe were brought by the Arabs in the twelfth century, but it was not until the Venetian, Marco Polo's, voyage to the extreme East, in 1295, that we knew of their place of origin. However, they remained in a state of rare exceptions up to the beginning of the twelfth century, the time at which the Dutch began to carry on a regular trade with the East. They were only brought on to the European markets during the following century.

**18. European Porcelain.**—Throughout the seventeenth century strenuous efforts were made to reproduce Chinese porcelain, but without success, because nothing was known of the raw material, kaolin, which Nature has placed so liberally at the disposal of the Chinese. It was not until 1709 that Böttcher, assisted by the advice of Tschirnhaus, succeeded in manufacturing porcelain in the castle of Frederick Augustus II., King of Poland and Elector of Saxony, at Meissen, Saxony. There is a touch of romance attached to the history of this discovery.

Böttcher, born in 1682 at Schleiz, became a student of pharmacy at Berlin, and devoted himself to works of alchemy, which brought so much attention on him that he judged it expedient to flee into Saxony to prevent Frederick III. of Prussia from getting hold of his person and his secrets. From Frederick Augustus II. he received a princely hospitality, which was afterwards changed to a strict supervision. However, about 1704, having entirely failed

in his attempts to convert the common metals into gold, he, by the aid of Tschirnhaus' advice, began to inquire into the secret of Chinese porcelain. After having first succeeded in manufacturing a reddish stoneware, he conceived the idea—so the legend informs us—of making use of a new white powder which he used to powder his wig. This was some kaolin from Aue (Saxony), which Schnorr, a forge master in that country, had recently sold lucratively for toilet purposes. The result was beyond expectation. From 1710 or 1711 Böttcher succeeded in manufacturing hard porcelain, and Frederick Augustus II. had workshops built at Meissen, over which he had control, and from these originated the celebrated porcelain which bears the name of that town. Worn out by intemperance, Böttcher, in 1719, died while still a young man. Tschirnhaus had preceded him to his grave in 1708.

In spite of the extraordinary means employed at Meissen to guard the secret of the new manufacture, it could not be kept for long. A foreman, Stöpzel, succeeded in escaping and founded a manufactory of porcelain at Vienna, in Austria. Stöpzel was in his turn betrayed in 1740 by a workman named Ringler, who sold the processes to the celebrated manufacturer of faience of Höchst on the Main. After many years' sojourn at Höchst, Ringler joined with the Strassburg manufacturer of faience, Hannong, and in 1775, they founded the factory for porcelain at Frankenthal; then those at Nymphenburg, near Munich (1756), and at Larisburg, near Stuttgart (1758). One day Ringler, who constantly carried his recipes on his person, being intoxicated, was robbed by several of his workpeople, who retailed his secrets throughout Europe, selling them at the highest prices they could get. Thus it was that factories were founded at Doccia, near Florence, Berlin (1750), St. Petersburg (1772), Copenhagen (1773), Rübensgrün, in Bohemia (1790), etc. On the other hand, the porcelain factories of Thuringia, Sitzerode, Volkstedt, Limbach, etc., the earliest date of which is 1762, were founded by the chemist Macheleidt, who, on his part, appears to have discovered the manufacture of hard porcelain fifty years after Böttcher.

If the researches undertaken throughout Europe to manufacture china proved for so long fruitless through want of kaolin,

they yet resulted in discovering a new kind of pottery—soft porcelain—a material somewhat resembling glass, and which does not contain kaolin. In 1693, Chicaneau, perhaps advised by Louis Poterat, of Rouen, first discovered this new kind of pottery at Saint-Cloud, near Paris, and for which a license of twenty years was granted him in 1702. It appears that another manufactory of the same kind existed at Lille from 1708 to 1720. In 1735 factories of soft porcelain were established at Chantilly and Mennecy, near Essonne, and, later, those of Sceaux, Tournay, Strassburg, Saint-Amand, Arras and Vincennes. In 1754 this last manufactory was purchased by Louis XV., who transported it to Sèvres in 1756.

Notwithstanding the considerable progress which the manufacture of French soft porcelain made, the Sèvres factory, in 1761, purchased the secret of the manufacture of hard porcelain from Hannong of Strassburg, who had recently become the proprietor of the celebrated porcelain manufactory of Frankenthal. However, the first trials were only made in 1765 at Bagnolet by Guettard, who had just discovered near Alençon a bed of rather impure kaolin. The porcelain thus manufactured was grey and of a poor quality.

Such was the condition of the porcelain industry in France when, about the year 1765, Mme. Darnet, the wife of a surgeon at Saint-Yrieix, by chance discovered the famous kaolin beds situated near this town, a discovery which caused the total abandonment of soft porcelain, and assured the supremacy of hard porcelain in France. From 1774 the manufacture of the latter was in full activity at Sèvres. Under the protection of Turgot the first factory was established at Limoges in 1771, followed by a second in 1793, and by several others after 1797; on the other hand porcelain manufactories increased at Bayeux (1802), at Chantilly (1805), at Vierzon (1815), etc.

In England the manufacture of a kind of soft porcelain was commenced about 1745 at Chelsea, but the first regular manufacture of English soft porcelain, in 1751, is due to Chaffers of Liverpool. This was obtained by using phosphate of lime as a flux. The discovery of the vast Cornish beds of kaolin, in 1768, improved the manufacture, which was introduced into

Staffordshire in 1772, and made considerable progress. While in France the discovery of kaolin had induced the abandonment of soft porcelain, the latter, as will be observed, continued to be manufactured in England to the exclusion of hard porcelain.

**19. Contemporary Ceramics.**—This brief summary of ceramics brings us to the beginning of the nineteenth century. We have seen that its origin is lost in the obscurity of time, and that under the form of fired bodies it was the first industry of man, after he had mastered the process of firing, and this definitely assured to him the conquest of the earth. We have seen how slow his beginnings were, how the labours of several generations have sometimes been abruptly destroyed, only to be taken up again some centuries ahead. We have seen that in order to be brought to the level it had attained at the beginning of the nineteenth century, the sum of the efforts of all nations was necessary, each of whom in turn held the first rank in the intermittent march of civilisation. After the Egyptians and Assyrians came the Persians, Greeks and Romans, then the Chinese, Arabs and Moors, and finally the Italians, French, Germans and English. We have seen the extraordinary part which chance has sometimes played, and that of perseverance, of no less importance, of the pertinacity, and even devotion of some men, for if ceramics has had its victors, it has also had its martyrs.

To the nineteenth century belonged the task of uniting the different branches of the ceramic art, of substituting for tradition and the secrets of manufacture the principles of science, of transforming the craft into an industry, and of placing the art, the privilege of a few, at the disposal of all.

We have seen at the beginning of the nineteenth century that the terra cotta employed in building had not made any marked progress since the beginning of the fifth century, and that this manufacture was carried on according to the traditions left by the Romans, our masters in the art of building. These latter only employed terra cotta concurrently with stones, nearly always covering the pieces with glaze, and only very rarely making use of them for decorative purposes. But from the beginning of the Renaissance the position of terra cotta becomes

less subordinate: the framework and decoration were always done in stone, but in the smooth parts of the walls remarkable bricks were left with their natural colouring. This was the kind of construction which prevailed in France when neither very rich nor very poor in stone, and in the southern countries of Europe.

But this is not true for the North, particularly for the Netherlands, England, Germany and the United States. In many of the buildings erected in these countries stone is excluded, and terra cotta, without any glaze, is used entirely for the building and decoration. Doubtless stone will always remain one of the necessary elements in building, and the countries which are well supplied with it may be esteemed fortunate, but the use of ornamental bricks will spread more and more. For this it is enough that the architects should break with existing traditions and apply themselves to arrange from the commencement of the building the decorative parts of which they will later have need, instead of only concerning themselves with the decoration when the huge piece of masonry is achieved.

In iron construction, which dates from the middle of the nineteenth century, and which had its origin in France, terra cotta is called upon to play an important part, serving the purpose of filling the metallic skeleton, and of a decorative element, in the same way as faience, stoneware or porcelain. The universal exhibitions of 1878 and 1889 have shown the use to which this new kind of building can be put, but it is to be regretted that, with some rare exceptions, those brilliant examples have not, up to the present, been more followed.

The employment of mechanical presses, and a firing raised to a more elevated temperature, have for the last forty years greatly improved the quality of solid bricks. From this point of view Germany occupies the first rank. The ornamental bricks which are used have a power of resistance, a vigour of form, a uniformity of colouring, which have nowhere yet been equalled. The hollow bricks known long ago were not used because of the difficulty in their manufacture, when Borie in 1885 invented a tool, since that time everywhere imitated, which has been the starting-point of their frequent use. Moreover,

a Frenchman, Gilardoni, about the same time invented a bonding tile, which, by the lightness of its pose, tends more and more to oust the ancient patterns. We must also mention the tiles which, in the south of France especially, have attained a hardness and beauty of appearance which they never possessed in the preceding centuries.

The manufacture of drainage pipes, which have rendered such important service to agriculture, originated in England at the end of last century, but it is only in the first half of ours that their use spread into Europe. But the use of terra cotta for domestic purposes tends, on the other hand, to diminish before the competition which is created by faience and porcelain. In spite of the imitations made during this century of the beautiful decorative pottery of the Greeks, their artistic character has a tendency to confine itself to flower vases, and to a reproduction of statues, which, from an artistic point of view, leaves much to be desired.

Refractory ware is an invention of the nineteenth century. Doubtless refractory bricks were previously distinguished from those which were not, but the wisdom of the ceramists was confined to this observation alone. The scientific knowledge of the properties of raw materials, the accuracy of the mixings, have created an industry which has rendered such considerable progress in metallurgy and the chemical arts possible. This industry originated in England, it spread from there into Belgium, France, Germany and the United States—to mention only the chief manufacturing countries. It is, however, chiefly to Germany that we owe the scientific researches which have taught us the properties of refractory materials at high temperatures.

We have seen that at the beginning of the nineteenth century faience manufactures were only carried on in England, where, according to the processes of Wedgwood, faience of a hard body, concealing itself under the names, at that time much in fashion, of iron stone and opaque porcelain, was manufactured. The great success of this kind of pottery at the beginning of the century was the cause of the establishment of similar faience factories in France, Germany, Belgium, Holland, Sweden, Denmark, and more recently in Spain, Russia,

Italy and the United States. However, it was not until the second half of the century that this manufacture assumed any considerable importance on the Continent, being localised in several large factories. The English manufacture became concentrated in the Potteries (Staffordshire), being assisted by the raw materials there, which, with the exception of silex, are all found in English soil. The production of this ware, which is of considerable importance, has thus been preserved, and is the means of an active export trade.

English factories, and also those of the Continent, manufacturing chiefly dinner ware, and having to contend with the competition of china, have, by successive improvements, notably increased the hardness and solidity of their wares, and have found out, by means of clever decoration, which has had a considerable run, how to conceal the defective whiteness of the body.

More recently several faience manufacturers have entered upon architectural decoration, and manufacture wall tiles which have certainly become one of the most beautiful and most powerful means of the interior ornamentation of our dwellings.

Stanniferous faience, which was in a state of decay at the beginning of the nineteenth century, has again been manufactured during the last fifty years. Its applications were at first confined to the manufacture of stoves; then came imitations of old Moresque, Italian, French, Dutch faience, and finally their employment in monumental decoration, when they were united to terra cotta.

It was also reserved to our century to revive the ancient Persian faience of a silicious body and transparent alkaline glaze. This body, owing to the brilliance and incomparable richness of its colours, is certainly, from a decorative point of view, the most beautiful which ceramic art has produced. This renovation is of recent date, for it was not until 1861 that Deck, the famous French ceramist, reproduced for the first time the celebrated turquoise blue which was so appreciated by the Persians.

In the same manner as faience, we have seen that the manufacture of stoneware had taken refuge in England at the end of last century, where it was carried on extensively, and attained to an extraordinary degree of perfection, thanks chiefly to Messrs. Doulton & Co., whose name is still connected with that kind of

pottery. For the last forty years factories have also increased in other parts of Europe and in the United States. At the present time artistic stoneware, manufactured principally in England, France, Japan, Germany, Belgium and the United States, enjoys extraordinary favour.

Stoneware has still another application, less brilliant but probably more lasting, in drain pipes and sanitary apparatus, thus making ceramics an indispensable auxiliary of the new science of hygiene.

Moreover its use has become considerable in factories of chemical productions, owing to its resistance to acids. Finally it has established important works which manufacture paving tiles in stoneware, either plain, or decorated by incrustation of coloured bodies with a very beautiful effect.

The manufacture of hard porcelain has continued to develop during the course of the century. In addition to the countries of the extreme East and a few isolated factories, the greatest centres of production are: in France, Limousin; in Germany, Saxony and Silesia; in Austria, Bohemia. Besides being used for dinner ware and decorative pieces, it is also employed in laboratories, and, owing to its non-conductibility, in electric installations. Some applications of it have also been made in monumental decoration.

The high temperature of the firing of its glaze, which greatly limits the number of the colours which can be used at a high fire, has instituted a search for a more fusible composition in order to facilitate decoration. Some attempts in this direction have been crowned with success at the manufactories of Sèvres and that of Berlin.

As to the old French soft porcelain, abandoned at the end of last century, this is no longer the object of a regular manufacture. On the other hand, English soft porcelain continues to be solely manufactured in Staffordshire, where it is, like faience, the object of an important manufacture. We must also mention the manufacture, during the last fifty years, of a kind of porcelain, usually without glaze and resembling stoneware, several varieties of which exist and are known under the name of Parian and Carrara, from analogy with the marbles of Paros and Carrara, and porcelain buttons, which are the monopoly of a few factories.

After this short *résumé* we can see that the ceramic industry and arts have made considerable progress in the course of the nineteenth century, due principally to the improved means of production, also to chemistry and to the more exact knowledge of the properties of raw materials. However, we need not believe, as it has sometimes been pretended, that ceramics have said their last word. Doubtless, in certain of its applications it seems to have arrived near perfection, but in others much still remains to be done, and the progress of other industries will give rise to new applications. Finally, we must observe that there still exist many treatments in which pottery could, with advantage, replace the materials now employed, on account of their indestructibility or the brilliance of their decoration.

# CHAPTER II.

## RAW MATERIALS OF BODIES.

SUMMARY I.—*Clays:* (*a*) Pure Clay: Composition and Chemical Properties—Physical Properties—Formation of Pure Clay. (*b*) Natural Clays: Formation of Natural Clays—Materials mixed with Clays—Materials not separable by Washing—Materials separable by Washing—Accidental Impurities—Classification of Clays—Kaolins—Refractory Clays—Vitrifiable Clays—Fusible Clays—Analyses of Clays.

SUMMARY II.—*Various Raw Materials:* Classification: (*a*) Materials Analogous to Clay. (*b*) Agglomerative and Agglutinative Materials. (*c*) Opening Materials: Use and Nomenclature—Silicious Materials—Sands—Calcareous Materials—Carbonaceous Materials—Pulverised Fired Bodies called Grog or Rough Stuff. (*d*) Fusible Materials: Use and Nomenclature—Alkaline Fluxes—Calcareous Fluxes—Various Fluxes. (*e*) Refractory Materials.

SUMMARY III.—*Trials of Raw Materials:* (*a*) Trials of Clays: Methods of Trial—Trials on the Constitution of Clays—Chemical Analysis—Special Estimation—Trials of Texture, Plasticity, Fusibility. (*b*) Trials of other Raw Materials.

### 1. CLAYS.

#### (*a*) *Pure Clay.*

**20. Composition and Chemical Properties.**—We have seen that in ceramics under the general name of "clays" are included all the rocks or natural earth which, after mixture with water, form a plastic body, hardening under the influence of heat. They owe these properties to hydrosilicate of alumina, which enters into their composition in varying proportions. Silica, alumina and water are, in fact, susceptible to form different combinations, but among the latter there is one which, in the constitution of clays, plays quite an overwhelming part; this is hydrated bisilicate of alumina, represented by the chemical formula:—

$$Al^2O^3\ 2SiO^2\ 2H^2O,$$

designated under the name of kaolinite in mineralogy, and pure clay in ceramics. Other hydrosilicates of alumina which can enter into the composition of clays must be considered under the same head as other substances which, mixed with pure clay, form

numerous varieties of natural clays. Pure clay is formed, therefore, by 1 element of alumina, 2 of silica, and 2 of water, the corresponding weight in percentages being 39·77 per cent. alumina, 46·33 per cent. silica, and 13·90 per cent. water. In a moist atmosphere pure clay absorbs a certain quantity of water, varying from 3 per cent. to 9 per cent., according to the hygrometric condition and the size of the molecules.

When submitting pure clay to the action of an increasing heat all hygrometric water is eliminated at a temperature slightly higher than 100°, then it begins to become decomposed about 350° to 400°. This decomposition continues slowly up to about 650° to 700°. At this temperature the hydrosilicate of alumina is completely destroyed, water has been eliminated, and the mixture remaining is composed of 46·19 per cent. aluminium and 53·81 per cent. silica. It is, therefore, impossible to reconstitute the original hydrate or to restore the plastic qualities of pure clay to this mixture.

If the temperature is still raised towards 700° or 800°, the silica and alumina begin to combine to form a new anhydrous silicate of alumina. This combination appears to be complete between 1,100° and 1,200°. Towards 1,500° the first symptoms of vitrifaction appear, then the mass grows soft, and ends by dissolving.

The alkalies, soda and potash, in solution, after a prolonged firing, come into contact with the hydrosilicate of alumina and transform it into double silicate of potash and alumina. The same reaction is produced when the alkalies are in a solid state or in the form of carbonates, but in that case the temperature must be raised to the point of fusion of the mixture. On the other hand, anhydrous silicate of alumina is not attacked by alkalies.

Dilute acids have no influence on pure clay, but in a concentrated form hydrochloric acid and sulphuric acid displace silica from its combination at a temperature of 250° to 300°. They act in the same way, but more slowly, on anhydrous silicate of alumina. Up to the present time it has been impossible to obtain pure clay synthetically, that is to say by direct combination of its elements, alumina, silica and water.

Brongniart, Malaguti and more recently Salvetat and Bischoff had approved of the following formula for pure clay :—

$$2Al^2O^3 . 3SiO^2 . 4H^2O ;$$

but the works of Forschammer, Schloesing, Hautefeuille, Seger, of MM. Le Chatelier and Vogt, have with certainty confirmed the composition given previously, and this is now adopted by all ceramists.

**21. Physical Properties.**—The two physical properties characteristic of pure clay on which ceramic arts and industries are based are *plasticity*, which is obtained by its mixture with water, and its *hardening* under the influence of heat.

If an increasing proportion of additional water is added to a dry powder clay, that is a clay only containing its hygrometric water, a body is obtained which is more and more plastic. Then, the quantity of water increasing, the body becomes fluid, and the plasticity diminishes until it altogether disappears.

For a long time the causes of this plasticity were unknown, but the recent researches of Messrs. Johnson & Blake, and especially those of MM. Bidermann & Herzfeld, have confirmed the view that this remarkable property must be attributed to the extreme fineness and to the laminated form of the grains of pure clay. Certain clays having exactly the same chemical composition can yet differ considerably from the point of view of plasticity. Microscopic examination has shown that these differences correspond to the variation in size of the grains of hydrosilicate of alumina, the plasticity becoming greater and greater in proportion as the volume of the grains diminish.

Moreover this property is not peculiar to clay, for it can be observed that all minerals, if reduced to a sufficiently impalpable powder by the addition of a liquid, produce bodies having a certain amount of plasticity. The fact is clearly explained by the molecular attraction, which can only be obtained when the molecules are extremely close together, and consequently very minute.

However, this observation would not be sufficient to explain the much greater plasticity of clay in relation to the majority of other pulverulent minerals. The difference proceeds from the fact that pure clay is in the form of lamellar crystals entangled one with the other. This form allows the grains to be closer together than if they were polyhedral or spherical, and this coming together has the effect of increasing the attraction in a strong degree.

It is therefore seen according to this theory that the plasticity,

instead of being a special property, is simply the result of molecular attraction, and that like clay all bodies which are made up of laminated particles must become plastic when they are reduced to a sufficiently impalpable powder. This deduction has been verified by M. Vogt as regards mica. In reducing this mineral, which is made up of thin layers, very laminated, to the form of an impalpable powder, and adding water, he has succeeded in obtaining a body having a plasticity which can be compared with that of clay.

From this it can easily be understood what happens when water is added to pure clay in the form of a dry powder. In the latter the crystals are mingled in all directions, in consequence leaving the maximum amount of space between them. By the addition of a sufficient quantity of water, the molecules of which take their place between the grains of clay, the latter are enabled to change their places, to obey molecular attraction, and to move parallel to each other. This grouping is evidently assisted by the manual or mechanical kneading of the body, which fact explains the increase of plasticity which is observed every time a clayey body is subjected to mechanical work.

It is also clear that if a certain quantity of water is necessary to allow the grains to become displaced, and consequently to give plasticity to the body, an excess of water by driving the grains further away diminishes their attraction, and at a certain limit ends by destroying it entirely.

By mixing other liquids than water with clay powder very different degrees of plasticity are obtained. Fat liquids such as oils seem to make a more plastic body than water, especially if the clay has previously been dried to take away from it the hygrometric water. On the other hand, alcohol, ether and essence of turpentine produce bodies of little or no plasticity. By mixing a clay body and water with glycerine the water becomes gradually absorbed by the glycerine, the clay loses its plasticity and becomes pulverulent.

If a clay body mixed with water is left in a dry atmosphere, the water evaporates in a progressive manner. As long as the body preserves a sufficient plasticity, the departure of the water results in the grains of clay coming closer together in the proportion of the volume of water taken away. This diminution

in volume of the clayey body during the desiccation, the immediate consequence of plasticity, is known in ceramics as "shrinking". When sufficient water no longer remains to allow the grains of clay to become displaced, the shrinking ceases and the evaporation of the last traces of water induces the formation of voids in the interior of the mass.

But the dry body thus obtained no longer resembles the original powder. It forms a resisting mass of a greater density, which is apparent. The displacement and re-arrangement of the grains of clay parallel to each other, as well as the shrinkage during desiccation, have sufficiently drawn the grains together to allow the molecular attraction to continue after the departure of the water in spite of the voids formed. This is not the case with the mineral powders, which do not possess the lamellar form of clay, since these, after having acquired a certain amount of plasticity by their mixture with a liquid, become dismembered and fall into powder when the liquid disappears.

We have seen that at a temperature slightly higher than 100° the hygrometric water was in its turn eliminated, and that the hydrosilicate of alumina began to become decomposed at about 400°. This decomposition results in the disaggregation of the crystals, and the complete loss of their plastic properties. If the temperature continues to rise, towards 700° or 800° the silica begins to combine with the alumina, and an anhydrous bisilicate of alumina is formed. This combination continues slowly in proportion as the temperature increases, and produces compression of the grains of the original clay up to about 1,200°, when the mass becomes compact. Then a second shrinkage results during the firing. The silicate of alumina thus formed is a hard amorphous body which constitutes the essential element of all ceramic productions.

**22. Formation of Pure Clay.**—According to the theory generally admitted, pure clay is the result of the decomposition, under the influence of water and carbonic acid, of certain eruptive silico-aluminous rocks, the composition of which can be represented by the general formula,

$$Al^2 O^3, RO, nSiO^2,$$

$Al^2O^3$ representing the alumina, sometimes mixed with a small quantity of ferric oxide ($F^2O^3$), or rarely of manganese oxide

($Mn^2O^3$); RO can be potash, soda, lime or ferrous oxide (FeO), these bodies being generally mixed, but one of them always being in a preponderating proportion; finally $nSiO^3$ represents variable contents of silica.

Decomposition takes place according to the general formula:—

$$\underbrace{Al^2O^3,\ RO,\ nSiO^2}_{\text{(Silico-aluminous Rock)}} + \underbrace{2H^2O}_{\text{(Water)}} = \underbrace{Al^2O^3,\ 2SiO^2,\ 2H^2O}_{\text{(Clay)}} + \underbrace{RO\ (n-2)SiO^2}_{\text{(Silicate).}}$$

The silicate $RO(n-2)SiO^2$ is generally partly soluble, so that there only remains clay mixed with the RO insoluble bases and a certain quantity of silica.

Among the silico-aluminous rocks, which are admitted to be susceptible to the producing of clays, the most important are feldspathic rocks, granites, porphyry, gneiss, eurites, mixtures of feldspath, of quartz, and sometimes of mica. Feldspar itself is an anhydrous silicate of alumina and of alkalies, potash and soda. There are different varieties of feldspar, the two principal of which are orthose with base of potash, and albite with base of soda.

The chemical formula of orthose is:—

$$K^2O,\ Al^2O^3,\ 6SiO^2,\ \text{or}\ K^2Al^2Si^6O^{16},$$

that is a centesimal composition of 65·4 per cent. of silica, 18 per cent. of alumina and 16·6 per cent. of potash.

The formula for albite is:—

$$Na^2O,\ Al^2O^3,\ 6SiO^2,\ \text{or}\ Na^2Al^2Si^6O^{16},$$

or 68·5 per cent. of silica, 19·62 per cent. of alumina and 11·81 per cent. of soda. These two kinds of feldspar are sometimes found mixed.

In applying the preceding general formula to orthose we see that decomposition would take place after the following manner:—

$$\underbrace{Al^2O^3,\ K^2O,\ 6SiO^2}_{\text{(Feldspath orthose)}} + \underbrace{2H^2O}_{\text{(Water)}} = \underbrace{Al^2O^3,\ 2SiO^2,\ 2H^2O}_{\text{(Clay)}} + \underbrace{K^2O,\ 4SiO^2}_{\text{(Silicate of potassium).}}$$

Some chemists do not allow the formula given previously $K^2O,\ 4SiO^2$ for alkaline silica, the second result of the de-

composition of the feldspar, but employ for it the formula $K^2O$, $3SiO^2$, the fourth equivalent for silica being found in the free state, and can either remain mixed with the clay or be taken away by water at the same time as the alkalies.

This theory of the formation of pure clay by the decomposition of feldspathic rocks is confirmed by numerous examples of rocks, the decomposition of which continues to take place in our day. When the latter contain lime, there is found in addition carbonate of lime, which, carried away by the water and then deposited in sedimentary beds, has formed numerous calcareous beds, occasionally of a considerable thickness, which are as widely distributed as those of clay. The important part which the decomposition of feldspar plays in the formation of sedimentary beds can be estimated by observing that nearly three-fourths of the known surface of the earth is formed of gneiss and granite containing from 60 to 90 per cent. of feldspar.

The variations in the composition of these rocks, as well as in the circumstances of the composition, also explain the formation of other hydrated silicates of alumina — halloysite, bauxite, lenzenite, severite — having the same composition as kaolinite, allophane, which apparently corresponds to the formula $SiO^2$, $Al^2O^3$, $nH^2O$, pyrophillite, the composition of which is $5SiO^2$, $Al,O^3$, $H^2O$, and hydrated silicate of alumina, probably $4SiO^2$, $Al^2O^3$, $nH^2O$ which is found in calcareous marls. However, it is also possible that some of these rocks may be direct eruptive productions, as some geologists suppose.

### (*b*) *Natural Clays.*

**23. Formation of Natural Clays.**—In Nature we meet with a certain number of clay beds in which kaolinite is found mixed with the débris of rocks which have produced it. At other times these beds, instead of remaining intact in their original place, have been displaced by currents of water and carried to a short distance, where they form sedimentary beds, more or less polluted by the impurities suspended in the water. Such is the *first phase* of the formation of clays, characterised by the decomposition of the silico-aluminous rocks, and the de-

posit on the place, or at a short distance from the place, of origin of the original clay, or kaolin.[1]

The differences in the composition of the original rocks, as well as in the foreign matters which are found mixed with them, explain the considerable variations which are observable in the composition of primitive clays. However, they have properties by which they are easily recognised, especially if by grinding and decantation the kaolin is separable from the impurities which it may contain. By this means a whitish powder is obtained, more or less tinted with yellow, light red, or grey, soft to the touch, although a little granulated, which, by the addition of water, forms a fairly plastic body, emitting that earthy smell which is so singular and so characteristic. Examined under the microscope, it is seen that it is formed of very tenuous flat crystals of kaolinite, mixed with a variable quantity of débris of other crystals.

If the currents, instead of simply displacing the kaolin, carry it rapidly away in their course, or if some existing beds are invaded by the course of the water, those materials held in suspension go down into the beds of the torrents; jostled, tossed, pommelled amongst the pebbles, they end by becoming pulverised and transformed into impalpable mud, which is deposited in the mouths of the stream of water, or in passages where the speed of the water is cut off after having left the heaviest rocks on the way.

Sometimes these currents of water have hollowed their beds in the midst of rocks which are too hard to be sensibly disaggregated by their course, the materials in suspension have then remained free from any mixture, and, becoming deposited, have formed beds of plastic clay, that is to say, kaolinite of extremely fine crystals.

But in the majority of cases the torrents have traversed over sandy, calcareous or ferruginous pieces of ground, which they have hollowed out and carried along in their course. At other times they have come in contact with pieces of water burdened with mud of various composition, or vegetable débris. When still water is reached all these materials held in suspension

[1] From the Chinese *kao*, high, and *ling*, hillock, doubtless an allusion to the position of the beds of this clay in China.

are deposited simultaneously, and have resulted in beds very different in composition, superposed by layers also differing among themselves according to the circumstances of the passage of water and the course of the torrent.

In this manner are formed sandy, ferruginous, calcareous and peaty clays.

Such is the *second stage* of the formation of clays, characterised by the mechanical pulverisation of kaolinite and the deposit of the most diverse clays at a great distance from the original rock.

In our day circumstances do not lend themselves any longer to the formation of deposits of plastic clay, but we are always seeing that of more or less impure clays which are deposited in the mouths of certain rivers, in lakes, or in the sea.

In this second phase of the formation of clays, the hydrosilicate of alumina, under the influence of mechanical pulverisation in the midst of the water, has undergone an important modification. Examined under the microscope, it presents itself under the form of impalpable grains, very unctuous to the touch, variable in colour; by the addition of water a very plastic and flexible body results, a property which, added to the omission of an earthy smell, easily enables one to recognise clays and to distinguish them from other minerals.

**24. Materials Mixed with Clays.**—The materials which, mixed with pure clay, form numerous varieties of natural clays, can be classed under three divisions:—

(1) Débris of non-decomposed rocks, which are usually of granite, porphyry, gneiss, quartz and mica.

(2) Other products of decomposition: carbonate of lime, magnesia, iron, oxide of iron, etc.

(3) Materials introduced by the streams and depositing themselves at the same time as the clay.

For this geological classification it is preferable, from a ceramic point of view, to substitute the following, based on the physical condition of the materials mixed with the clays:—

(1) Materials in impalpable grains which form an integral part of the clay, and which it is impossible to separate from it by grinding: silicates of alumina, mica, hydrated and quartzy

silica, carbonates of lime, magnesia, oxides and sulphates of iron, organic matters.

(2) Materials in the form of more or less fine grains spread through the clay with a fair degree of uniformity, but inseparable by grinding: quartz, mica, feldspath, carbonates or sulphates of lime or of magnesia.

(3) Materials of varied form disseminated irregularly in the clay, separable by grinding or often even mechanically, which consist of accidental impurities: stones, shells, gypsum, sulphur, and iron ore.

25. **Materials not Separable by Grinding.**—*Silicates of alumina.*—The silicates of alumina which can be found mixed with kaolinite are very difficult to recognise, because there is no method of chemical analysis by which they can be separated. M. Le Chatelier proposed to seek to distinguish the different hydrosilicates of alumina by the temperature to which they must be brought to induce their dishydration.

By this method M. Vogt has been able to prove the presence of kaolinite in all clays, and in a few rather rare cases its mixture with other hydrosilicates of alumina, particularly of allophane.

However interesting these researches may be from a scientific point of view, ceramically speaking, they are not very important, since the presence of silicates of alumina in pure clay does not modify its plasticity, and these, like the plasticity, are neutralised under the action of heat, giving place to a mixture of alumina and silica, the exact proportion of which is indicated by analysis.

*Feldspar and Mica.*—It was generally admitted that the alkalies contained in clays were found in the state of impalpable powder of feldspar. M. Vogt has shown that this opinion is erroneous, and that alkalies exist in clays in a state of pulverulent mica. He has proved that, if we knew it, mica in coarse grains is not, or is very little, assailable by sulphuric acid, but it becomes so when reduced to an impalpable powder. When a clay is acted upon by this concentrated acid, the impalpable clay and mica which are dissolved are separated from the one part, and the feldspar and quartz from the other. This distinction is somewhat important, since the pulverulent mica is plastic, whereas the feldspar powder is not. The variety of mica which is met

with in clays is a potassic mica, known in mineralogy as "muscovite".

*Silica.*—This can be found mixed with clay, either in the form of hydrated silica or in the state of quartzy crystalline silica. The presence of hydrated silica in certain clays is not absolutely proved, or can be found there in very small proportions, and has no influence on its plasticity. This hydrate disappears at a temperature just above 100°. The quartzy silica which is met with, on the contrary, nearly always is the result of the pulverisation of the quartzy rocks. The coarser parts are removed by grinding, but there are some the tenuity of which is so great that it is impossible to separate them by this process. They act as an antiplastic material.

*Carbonate of Lime or of Magnesia.*—Carbonate of lime mixed with clay has two different origins. It may proceed from the decomposition and from the pulverisation of rocks containing lime, or it may be deposited by waters holding carbonate of lime in dissolution. It is known that water charged with carbonic acid can dissolve a certain quantity of carbonate of lime. If this solution is mixed with clay, the latter retains the carbonate. Kaolins do not retain more than 2 per cent. of carbonate of lime in solution, while plastic clays can absorb from 10 to 20 per cent. of it. Carbonate of lime diminishes the plasticity, but in a less proportion than quartz. Carbonate of magnesia is less frequently met with in clays; it proceeds from the disaggregation of magnesia rocks, and acts like carbonate of lime.

*Iron Oxides.*—These are found in clays, either in the state of anhydrous ferric oxide or in the state of hydrated ferric oxide. The ferric oxide generally proceeds from the decomposition of ferruginous rocks, and is in the form of carbonate of iron. Sometimes also it penetrates into the clay in solution, when it is combined with organic acids, such as "humus". In both these states it can only subsist in the clay free from the contact of air, otherwise it is transformed into hydrated ferric oxide, the form in which it is nearly always found. These various combinations of the oxide, as well as hydrated ferric oxide, colour the clay with different tints, which are transformed into yellow or red, according to the proportion of oxide of iron, when brought to a temperature of 100°, at which

these combinations disappear at the same time as the hydrated ferric oxide loses its water of combination.

The oxides of iron do not appear to diminish the plasticity of the clay, and they increase its cohesion after firing. Certain clays can contain up to 2 per cent. and more of these. The beds of ferruginous clay can be deprived, entirely or in part, of the oxide of iron which they contain, while they are for centuries washed by waters containing organic acids in solution coming down from marshes or turfy deposits. Such is the case, for instance, with the present white clays of Vallendar, near Coblentz, and of Grossalmerode, in the Palatinate.

*Sulphide of Iron.*—Sulphides of iron appear to be formed in the beds of clay by the action, on carbonate of iron, of sulphuretted hydrogen, which is evolved from organic materials in decomposition. It can be disseminated in the clay, but usually it groups itself in the form of nodules, about which we will speak later.

*Organic Materials.*—Organic matter contained in clays may be due to three causes:—

(1) Infiltration of soil in the bed of clay, as has been previously explained.

(2) Deposit of clay in an estuary or marsh containing vegetable matter.

(3) Mixture of bituminous rocks.

In the first and third cases the proportion of organic matter is not very great, but in the second it may become considerable. Generally speaking, organic substances tend to increase the plasticity. When the clay contains a large proportion of them, they greatly augment the quantity of water which it absorbs, and consequently its shrinkage. They naturally disappear about 100°, and the carbon which remains is burnt during the firing.

*Various.*—Some chemists have supposed the presence of hydrate of alumina in clays. This is, however, not proved, and it is much more probable that the excess of alumina which has sometimes been declared is due to some silicates which are richer in alumina than kaolinite.

Moreover, sometimes clays contain, though in very small proportions, sulphate of lime, baryta, phosphoric acid, fluorine and some metallic sulphides. On rare occasions, and then in

very small quantities, we find oxygenated combinations of titanium, vanadium, molybdena, copper, chromium and some gold metal. Again, Forbes found 0·62 per cent. of titanic acid in a red clay, and Seger attributes to vanadic and molybdic acids the yellow and green settlings observed on some pieces of terra cotta manufactured from clays in the north of Germany. In the clays forming the soil of the town of Philadelphia a little less than one-millionth of gold is found.

**26. Materials Separable by Grinding.**—*Feldspar.*—This is only met with in considerable quantity in primitive clays. Being of laminated form, it can be scratched by quartz and fuses at porcelain heat in the form of milky glass.

*Quartz.*—When this is in sufficiently fine grains it is a most excellent antiplastic material. It mixes very well with clay, and mitigates its too great plasticity and shrinkage by imparting to it peculiar properties during the drying and firing. Its grains are either round, or broken irregularly, very hard, slightly transparent, and infusible at porcelain heat.

*Mica.*—This is found in the form of brilliant spangles, very small and flat, remaining for a long time held in suspension in water. It introduces alkalies into the clay in a small proportion. But in a much greater proportion it acts as an antiplastic material, because its laminated form disunites the clay and destroys the cohesion.

*Carbonates of Lime and of Magnesia.*—These substances, in grains of an appreciable size, are very injurious and render a great number of clays unfit for any use. During firing they become transformed into caustic bases, which afterwards increase in volume when absorbing moisture, and cause the pottery to split. The carbonates are easily recognised by the effervescence which they produce in coming in contact with acids. Finally, there are sometimes found in clays in the form of grains, though always in small quantities, calcium sulphate, invariably injurious, calcium silicate and magnesium silicate neutral substances and ferruginous compounds.

**27. Accidental Impurities.**—The impurities which are sometimes found in clays, either accidentally or irregularly dispersed, are not as a rule mentioned in the analyses.

Quartz or calcareous stones and silex are easily separated either by hand or by suitable machines.

Shells, of which the calcium carbonate is very noxious, contaminate a great number of clays; they can only be taken away by grinding. Sometimes there remains no more than the impression of the shell, the carbonate of lime being disseminated in the clay.

Gypsum is sometimes found in crystals of fairly large size and in lumps; it is easily separated.

Ferrous sulphide, which, as we have seen, is formed in the midst of the clay, does not remain dispersed, but becomes agglomerated in the form of brilliant crystals of a fairly pronounced yellow colour, with a metallic lustre. When these crystals are large they are easily removed, when they are small and numerous grinding must be resorted to. For coarse ceramic productions they may be left in the clay, but in the firing the sulphur is volatilised and the oxide of iron causes the materials around to fuse, thus forming cavities.

Iron ore, red hematite and yellow limonite are fairly frequent in plastic clays. The large pieces are easily separable, the others act like sulphide of iron, but without offering the inconvenience of causing the removal of sulphurous vapour in the firing.

**28. Classification of Clays.**—From a ceramic point of view a classification of clays has an interest for those clays alone which are used in the manufacture of pottery ware. Therefore we shall not treat of fuller's earth, saline clays, ochres, sand more or less fatty, of clayey marls, etc. It is expedient, moreover, not to take into account accidental impurities which may occur in them.

But even after these eliminations, the same difficulties are met with in the classification of clays as have been noted in the classification of pottery ware. The varieties of clays are extremely numerous, forming a continuous series from kaolin up to the very complex materials into which pure clay only enters in a small proportion, about which there is some hesitation in classifying them under the head of clays. As in the case of ceramic ware, it is expedient to avoid making hard and fast lines of demarcation, and to be content with mentioning the principal types without being concerned with the exceptions.

These observations are sufficient to show that a classification of clays based on their geological formation, however interesting it may be from a scientific point of view, has no value ceramically, and that it is convenient to consider clays in the state in which they are found in Nature without taking into consideration the conditions of their formation.

We have seen that clays can be divided into two classes, kaolins and clays properly so called, this distinction being based on the physical properties of hydrosilicate of alumina. In kaolins the grains of pure clay, being relatively less fine, are less plastic, lighter and of a less unctuous touch than in clays properly so called. The mere appearance and touch are usually sufficient for a ceramist to distinguish a kaolin from a clay. In cases of doubt one of the following two means of differentiation can be used: In mixing an equal volume of kaolin and of clay with a volume four to six times as large of concentrated sulphuric acid, the precipitation and clarification of the liquid takes place much more slowly in the case of the kaolin than in that of the clay; but if, after having drawn out the liquid water, some ammonia is added, the kaolin then forms a precipitate, whereas the clay does not. In subjecting dry bodies to the action of a moderate heat (800° to 1,000°) a much lighter and more porous mass is obtained with kaolins than with clays.

In each of these two classes the different kinds of clays are distinguished by the nature and contents of foreign substances mixed with hydrosilicate of alumina. From this point of view there is occasion only to consider five substances: Silica, whose chief action consists in diminishing plasticity; and four others — alkalies, oxides of iron, lime, and magnesia, which, with the exception of ferric oxide, increase the fusibility. The other substances only occur in proportions too small to considerably modify their properties and to make it worth while to take them into account in a general classification.

The class of clays properly so called being very extensive, it is better to divide it at once into three classes:—

1. Refractory clays,
2. Vitrifiable clays,
3. Fusible clays,

which, as their names indicate, are distinguished by the manner in which the clays resist the action of heat.

**29. Kaolins.**—Kaolins are chiefly found in the form of lumps in the midst of other rocks: pegmatites, gneiss, granites, porphyry. More rarely they are found in sedimentary deposits. It is only exceptionally that they can be used in their natural state, because of the numerous rocky débris, often ferruginous, which are mingled with their mass. A manual sorting must generally be resorted to in the working, followed by a process of grinding, so that the samples on which the trials and analyses are made are not usually natural products.

The principal kinds of kaolin are the following:—

*Pure Kaolins* do not contain more than from 5 per cent. to 6 per cent. of silica and 2 per cent. of fluxes, the proportion of each of the fluxes taken singly being not more than 1 per cent. They are always brought to this degree of purity by washing, and present themselves in the form of a white powder, occasionally slightly tinted with yellow, grey or red, and very unctuous to the touch. After firing they form a body of milky whiteness.

They are used in the manufacture of porcelain and fine faience.

*Alkaline Kaolins.*—The only difference between these kaolins and the preceding is that they contain a higher proportion of alkalies, which can mount up to 5 per cent., coming from the mixture of feldspath and mica. In the meantime the proportion of oxide of iron rises sometimes to 2 per cent.

They have the same use as the preceding, but it must be observed that a very careful washing results in taking away the greatest part of the alkalies.

*Silicious Kaolins.*—In these kaolins hydrosilicate of alumina is mixed in a considerable proportion with quartz in the state of impalpable powder. This content of silica depends greatly on the care bestowed in the washing, it can rise up to 20 or 25 per cent. These kaolins furnish a body of small plasticity, and are of a light granulous texture. They are used in the manufacture of porcelain and certain kinds of faience, but for bodies which have no need to be very plastic.

*Alkaline Silicious Kaolins* contain at the same time a con-

siderable proportion of alkalies and of silica, and partake of the properties and uses of the two preceding kinds.

*Ferruginous Kaolins.*—These kaolins contain a quantity of oxide of iron which is too great to give an entirely white body after firing.

When this content is not too high it is utilised in the manufacture of porcelain and faience of inferior quality. For a greater proportion they can be used in the manufacture of refractory productions, but on the condition that they have not too much alkali.

The chief beds of kaolin are:—

In *France.*—Saint-Yrieix, Aixe, La Jonchère, Coussac-Bonneval, Daumail-sur-Vienne, Condat, Isle, in Haute-Vienne; Beauvin, Les Collettes, Echassières, Diou, in l'Allier; Saint-Maurice, Serves, Hostun, in the Drôme; Tayac, Eyzies, Jumillac, in Dordogne; Espelette, in the Basses-Pyrénées; Azy-le-Vif, Saint-Pierre-le-Moutier, in the Nièvre; Bouillý, in the Marne; Saint-Etienne-de-Crossey, in l'Isère; Saint-Sorlin, in Saône-et-Loire.

In *England.*—St. Austell (Cornwall), Wareham (Dorset).

In *Austria.*—Petschau, Oberbriez, Kottinken, Tresmosna, Zettlitz, in Bohemia; Steine, in Carniolia.

In *Germany.*—Dölau, Lettin, Seilitz, Kölln on the Elbe, in Saxony; Hirschau, Tirschenreuth, in Bavaria; Gruenstadt, in the Palatinate.

In *Denmark.*—Bornholm.

In the *United States.*—Woodbridge and Aurbey, in the State of New Jersey.

In *China.*—Numerous beds of the Kiang-si.

And, finally, those of *Japan.*

**30. Refractory Clays.**—Clays are found in a sedimentary form, sometimes in rich and homogeneous beds, at other times in beds variable in appearance and composition. They always contain a certain proportion of water, which evaporates in a dry atmosphere.

Refractory clays are distinguished by a dull appearance, without a sign of vitrifaction, which they preserve when fired at hard porcelain heat (1,350° C.); they can be divided into three classes:—

*Pure Clays.*—In which hydrosilicate of alumina is only found mixed with a few per cent. of silica and some traces of fluxes. They

are of a more or less greyish white, very unctuous, plastic in a high degree, producing, after firing, a body of a fine "matt" white. Those found on the market are generally washed. They are used for the manufacture of faience and certain kinds of porcelain. The beds of these are, relatively speaking, rare, and the variations in composition which are met with in the same course necessitate a careful sorting.

*Refractory Plastic Clays.*—These are distinguished from the preceding by a higher proportion of fluxes, the latter, however, not being sufficient to cause vitrifaction at porcelain heat.

The proportion of silica can be raised to 20 per cent. They have usually a greyish or yellowish tint, rarely greyish. They are used in the manufacture of faience bodies, slightly coloured, and in that of refractory productions. These beds are fairly numerous, some are homogeneous and rich, others, on the contrary, necessitate a sorting.

*Refractory Silicious Clays.*—These are only distinguished from the preceding by a higher content of silica, which can amount to 50 per cent. Their plasticity is naturally less and their touch more or less granulous; their use is confined generally to the manufacture of refractory wares. The colouring is nearly always clear, generally greyish, sometimes yellowish. The beds of these clays are, relatively speaking, numerous, but this clay only comes from a summary sorting in the quarry.

Among the chief refractory clay beds we can mention the following:—

*France*—

Allier: Echassières.
Aube: Villenauxe, Vendœuvre, Montpothier.
Cher: Vierzon.
Dordogne: Mussidan.
Drôme: Saint-Vallier.
Eure-et-Loir: Abondant.
Gard: Uzès.
Gironde: Pessac.
Indre: Argentan.
Indre-et-Loire: Langeais.
Isère: Moirans.

Orne: Sées.

Puy-de-Dôme: Champ-blanc, Caupière.

Saône-et-Loire: Ecuisses.

Seine-Inférieure: Forges-les-Eaux, Gournay.

Seine-et-Marne: Montereau, Provins, Saint-Germain-Laval.

Vaucluse: Bollène.

Haute-Vienne: La Jonchère.

Vienne: Fleuré.

*Belgium*—

Andennes, Bouffioulx, Hauterage, Saint-Ghislain.

*Great Britain*—

Devon: Newton Abbot.

Dorset: Corfe Castle, Wareham.

Worcester: Stourbridge.

Northumberland: Newcastle-on-Tyne.

Lancashire: St. Helens.

Wales: Aberdare.

Scotland: Garnkirk, Glenboig.

*Germany*—

Provinces of the Rhine and Palatinate: Hoehr, Hettenleidelheim, Gruenstadt, Vallendar.

Hesse-Nassau: Grossalmerode.

Saxony: Doelau, Lettin, Meissen.

*Austria and Hungary*—

Bohemia: Teplitz, Tremosna.

Moravia: Blansko.

*United States*—

Woodbridge and Trenton, in New Jersey.

**31. Vitrifiable Clays.**—These clays become vitrified more or less completely at porcelain heat (1,350° C.), but remain very nearly "matt" at faience heat (1,200° C.). They contain in consequence a higher proportion of fluxes than the preceding. According to the nature of what is found in them in a preponderating quantity, and their contents of silica, they are divided into plastic, ferruginous or calcareous alkalines. There can also be intermediary kinds: alkaline ferruginous plastics, for example. However, among these different kinds which can be met with in nature, there are two which, from their use and the number of their beds, deserve particular mention:—

*Vitrifiable Alkaline Clays*, whether plastic or silicious, serve as a base for the manufacture of artistic stoneware, sanitary ware, for chemical industries and paving tiles. Their colouring is generally deep bluish, inclining to violet or greyish, and in firing they give a body of which the tint varies from bluish white to a deep pearly grey, or from yellowish white to brown.

*Vitrifiable Ferruginous Clays*, nearly always silicious, can also be employed for the manufacture of sanitary stoneware, but are chiefly used for the making of paving tiles and vitrified bricks. Being of a yellow red, orange red or brown colour, they make a fired body of which the tint varies from brown to black.

It is well understood that vitrifiable clays, as well as refractory clays, can be used in the manufacture of terra cotta; it is sufficient if the temperature does not pass the point of the firing of faience.

The best known beds of vitrifiable clays, almost all alkaline, are the following:—

*France*—

Ardennes: Jandun.
Cher: Henrichemont.
Côte-d'Or: Pouilly.
Nièvre: Saint-Amand-en-Puisaye.
Nord: Ferrière-la-Petite, Fresnes, Sars-Poteries, Saint-Amand.
Oise: La Chapelle-aux-Pots, Savignies.
Saône-et-Loire: Ciry-le-Noble, Palinges, Paray-le-Monial.
Vosges: Jeanmesnil.

*Belgium*—

Saint-Ghislain.

*Great Britain*—

Wareham, Newcastle-on-Tyne, Longport.

*Germany*—

Vallendar, Hoehr, Bunzlau.

*Austria and Hungary*—

Kottiken, Ledez.

*United States*—

Woodbridge.

Finally, the beds of *China* and of *Japan*.

**32. Fusible Clays.**—Fusible clays vitrify, losing their shape at a low temperature, that of the firing of faience (1,200°). They

always contain rather a large proportion of silica. Some are, however, sufficiently plastic for use in the making of pottery ware, tiles, quarries, etc., while others, being too weak, can only be employed in the making of plain bricks. The chief flux is lime, alkalies being found almost always in a relatively small proportion. Among the numerous kinds of clay of this division four chief classes can be distinguished :—

*Plastic Ferruginous Clays*, very variable in colour, but generally rather dark, producing at firing a body the tint of which passes from orange red to brown.

*Plastic Calcareous Clays*, becoming effervescent when in contact with acids, very variable in colour, the fired body passing from orange to yellow, then to brownish or greenish yellow, according to the temperature.

*Silicious Ferruginous Clays*, presenting themselves in the form of crumbling earth, generally of a yellowish or reddish brown, the body of which assumes, at firing, a red colouring passing to a more or less deep reddish-brown.

Finally, *Silicious Calcareous Clays*, also in the form of crumbling earth, of a clearer tint than the preceding, becoming effervescent in contact with acids and forming wares having the same colouring as plastic calcareous clays.

The beds of fusible clays are very scattered in Nature. They are found in all countries, thus it is impossible to give even a very limited summary of them.

**33. Analyses of Clays.** — The following table gives some examples of analyses of clays. Too great importance need not be attached to the figures contained therein, or to the classification, because, on the one hand, in spite of the care bestowed in removing doubtful analyses, the methods employed by the different authors are variable, and do not admit of a rigorous comparison, and, on the other hand, the system of analysis does not give the exact information of rational analyses on the constitution of clays. But as this latter, based on the preliminary solution in concentrated sulphuric acid, is only too little used, we do not possess sufficiently numerous results to be able to reproduce them in the form of a table.

| Localities. | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Alkalies. | Body in Firing and Various. | Authors. |
|---|---|---|---|---|---|---|---|---|
| *Pure Kaolins.* | | | | | | | | |
| Zettlitz (Bohemia) | 43·12 | 36·30 | 0·46 | 0·19 | 0·19 | 0·42[1] | 17·78 | Bischof. |
| Kottiken (near Pilsen) | 49·91 | 35·99 | 0·63 | ,, | 0·30 | 0·76 | 12·34 | Seger. |
| Cornwall | 48·35 | 36·00 | 0·75 | ,, | ,, | 0·96 | 13·00 | Salvetat. |
| Schiraye (Japan) | 47·74 | 36·68 | 0·42 | 0·99 | ,, | 0·45 | 13·64 | Steinbrecht. |
| Dölau (near Halle) | 48·15 | 37·03 | 0·60 | 0·27 | 0·30 | 0·82 | 12·76 | ,, |
| Zettlitz (Bohemia) | 45·68 | 38·54 | 0·90 | 0·08 | 0·38 | 0·66 | 13·00 | Bischof. |
| *Alkaline Kaolins.* | | | | | | | | |
| Ledez (near Pilsen) | 49·16 | 36·73 | 0·81 | tr. | 0·18 | 1·18 | 12·41 | Seger. |
| Zettlitz (Bohemia) | 46·82 | 38·49 | 1·09 | ,, | tr. | 1·40 | 12·86 | Möller. |
| Tremosna (Bohemia) | 49·48 | 36·64 | 0·66 | ,, | 0·41 | 1·60 | 11·99 | Seger. |
| Les Colettes (Bes) (Allier) | 47·20 | 36·40 | 1·16 | 0·29 | 0·03 | 2·07 | 12·73 | — |
| Saint-Yrieix (Haute-Vienne) | 48·00 | 37·00 | ,, | ,, | ,, | 2·50 | 13·10 | Berthier. |
| Les Colettes (Bis) (Allier) | 46·91 | 37·08 | 0·87 | 0·22 | 0·04 | 2·63 | 12·35 | — |
| *Silicious Kaolins.* | | | | | | | | |
| Halle | 52·25 | 32·15 | 0·83[2] | 0·90 | ,, | 0·45 | 12·37 | Maercker. |
| Kaschkau | 56·72 | 31·07 | 0·59 | ,, | 0·22 | 0·51 | 11·18 | Möller. |
| Sonnewitz | 64·87 | 23·83 | 0·83 | ,, | 0·50 | 1·39 | 8·36 | — |
| *Alkaline Silicious Kaolins.* | | | | | | | | |
| Tong-Kang (China) | 50·50 | 33·70 | 1·80 | ,, | 0·80 | 1·90 | 11·20 | Salvetat. |
| Lettin | 57·08 | 29·94 | 0·65 | ,, | 0·49 | 2·26 | 9·87 | Möller. |
| Sy-Kong (China) | 55·30 | 30·30 | 2·00 | ,, | 0·40 | 3·80 | 8·20 | Salvetat. |
| *Ferruginous Kaolin.* | | | | | | | | |
| Gruenstadt (Palatinate) | 47·33 | 35·05 | 2·30 | 0·16 | 1·11 | 3·18 | 10·51 | Bischof. |
| *Pure Clays.* | | | | | | | | |
| Gay-Head (Massachusetts) | 46·54 | 38·00 | tr. | ,, | 0·50 | tr. | 15·17 | Salvetat. |
| Mussidan (Dordogne) | 49·10 | 37·60 | 0·30 | 0·30 | tr. | 0·15 | 12·30 | School of Mines. |
| Devonshire[3] | 49·60 | 37·40 | ,, | ,, | ,, | ,, | 11·20 | Berthier. |
| Meissen | 45·30 | 37·24 | 0·94 | 0·47 | ,, | 0·86 | 15·78 | Steinbrecht. |
| Gloukoff (near Chermikoff) | 46·35 | 37·00 | ,, | ,, | 0·15 | ,, | 16·50 | Salvetat. |
| Altwasser (Silesia) | 43·85 | 36·30 | 0·46 | 0·19 | 0·19 | 0·42 | 17·78 | Bischof. |
| Abondant (near Dreux)[3] | 50·60 | 35·20 | 0·40 | ,, | ,, | ,, | 13·10 | Berthier. |
| Echassières (Allier)[3] | 49·00 | 34·00 | ,, | ,, | ,, | tr. | 16·40 | — |
| *Refractory Plastic Clays.* | | | | | | | | |
| Ruditz (Moravia) | 53·68 | 33·64 | ,, | 0·22 | 0·06 | tr. | 11·95 | v. Gohren. |
| Dover (United States) | 57·60 | 31·52 | 0·88 | 0·30 | 0·16 | 0·45 | 9·09 | — |
| Argenton (Indre) | 48·40 | 30·00 | 2·20 | ,, | ,, | tr. | 18·00 | Berthier. |
| Pittsburg (United States) | 53·15 | 32·23 | 1·80 | 0·80 | ,, | ,, | 12·00 | — |
| Gross Almerode (Hesse) | 47·50 | 34·37 | 1·24 | 0·50 | 1·00 | tr. | 14·00 | Salvetat. |
| Klingenberg (Vosges) | 48·32 | 32·48 | 1·52 | 1·64 | tr. | tr. | 16·00 | — |
| Andennes (Belgium) | 49·64 | 34·78 | 1·80 | 0·68 | 0·41 | 0·41 | 12·00 | Bischof. |
| Klinkau (Bohemia) | 47·15 | 33·55 | 2·20 | 0·22 | 1·06 | ,, | 13·66[4] | Balling. |
| Ebernhau (Nassau) | 53·46 | 33·75 | 0·78 | 0·13 | 0·32 | 2·45 | 9·02 | Bischof. |
| Lautersheim (Prussia) | 49·00 | 33·09 | 2·10 | 2·00 | 0·20 | ,, | 13·56 | Salvetat. |
| Mühlheim (Prussia) | 47·74 | 36·00 | 2·57 | 0·40 | 0·33 | 1·05 | 11·81 | Bischof. |
| Brierley Hill (England) | 51·80 | 30·40 | 4·14 | 0·40 | 0·50 | ,, | 13·11 | Henry. |
| Hettenlheim (Bavaria) | 49·86 | 33·71 | 2·00 | ,, | 0·21 | 2·66 | 11·13 | Bischof. |
| Stannington (England) | 48·04 | 34·47 | 3·05 | 0·66 | 0·45 | 1·94 | 11·15 | Hambly. |
| Goettweih (Austria) | 48·39 | 35·60 | 3·12 | 0·82 | ,, | 2·54 | 11·72 | Knaffl. |
| Blanko (Moravia) | 50·75 | 30·52 | 2·75 | 1·23 | 1·02 | 2·01 | 11·88 | ,, |

[1] The proportion of water seems abnormal.

[2] The lime and magnesia are united.

[3] These analysis, being somewhat old, appear to be wanting in exactness.

[4] Including 0·10 sulphuric acid and 0·06 phosphoric acid.

| Localities. | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Alkalies. | Body in Firing and Various. | Authors. |
|---|---|---|---|---|---|---|---|---|
| *Refractory Silicious Clays.* | | | | | | | | |
| Montereau . . . . | 64·40 | 24·60 | tr. | ,, | ,, | tr. | 10·00 | Berthier. |
| Forges-les-Eaux . . . | 65·00 | 24·00 | tr. | ,, | ,, | tr. | 11·00 | ,, |
| Champ-blanc (Puy-de-Dôme) | 67·20 | 20·10 | tr. | ,, | ,, | ,, | 12·50 | Truhod. |
| Gournay (Seine-Inférieure) . | 62·50 | 26·60 | 0·15 | 0·20 | tr. | ,, | 11·00 | ,, |
| Beleu (Ardennes) . . . | 63·57 | 27·45 | 0·15 | 0·55 | tr. | tr. | 8·64 | Salvetat. |
| Gartsherrie (Scotland) . . | 59·48 | 28·95 | 1·05 | tr. | ,, | ,, | 11·05 | Schwarz. |
| Canny-sur-Thérain (Oise) . | 52·00 | 28·00 | tr. | ,, | 0·75 | ,, | 19·25[1] | Maret. |
| Lyonnet (Belgium) . . | 63·00 | 24·00 | 0·50 | ,, | 0·51 | ,, | 7·00 | ,, |
| Etrépigny (Jura) . . . | 70·00 | 18·50 | 0·50 | 0·75 | tr. | tr. | 9·96 | Salvetat. |
| Namur . . . . . | 72·64 | 19·49 | 0·85 | ,, | 0·06 | 0·85 | 7·47 | ,, |
| Canny-sur-Thérain (Oise) . | 56·00 | 26·00 | 0·50 | ,, | 1·60 | ,, | 17·90[2] | Maret. |
| Stourbridge . . . . | 65·10 | 22·22 | 1·92 | 0·14 | 0·18 | 0·18 | 10·07 | Percy. |
| Valendar (Prussia) . . | 65·27 | 24·19 | 1·00 | ,, | 2·02 | ,, | 6·75 | Salvetat. |
| Gottweith (Austria) . . | 65·60 | 20·75 | 2·00 | 1·65 | tr. | tr. | 10·00 | ,, |
| Bornholm (Denmark) . . | 72·50 | 19·50 | 1·00 | 0·18 | 0·50 | ,, | 5·92 | ,, |
| Montereau . . . . | 61·33 | 24·69 | 2·20 | 0·25 | 1·28 | tr. | 10·25 | ,, |
| Theuberg (Bohemia) . . | 58·39 | 27·94 | tr. | 2·74 | 1·00 | ,, | 10·49 | ,, |
| Kottinken (Bohemia) . . | 59·42 | 27·15 | 1·77 | ,, | 0·52 | 1·50 | 9·85 | Seger. |
| Oberkaufungen (Germany) . | 57·89 | 27·97 | 2·01 | 0·97 | 0·54 | 0·53 | 9·43 | Bischof. |
| Montabaur (Germany) . . | 61·71 | 27·08 | 0·67 | 0·15 | 0·29 | 2·06 | 7·59 | Eichhorn. |
| Niederpleis (Germany) . . | 58·32 | 28·05 | 1·89 | 0·72 | 0·75 | 1·39 | 8·66 | Bischof. |
| Glasgow . . . . | 66·16 | 22·54 | 5·31 | 1·42 | tr. | ,, | 3·14 | Brown. |
| *Vitrifiable Alkaline Clays.* | | | | | | | | |
| Hochr (Germany) . . . | 70·12 | 21·43 | 0·77 | ,, | 0·39 | 2·62 | 4·92 | Seger. |
| Laemmersbach (Germany) . | 64·53 | 24·59 | 1·01 | tr. | 0·34 | 3·06 | 6·55 | ,, |
| Ebernhahn (Germany) . . | 60·76 | 26·84 | 0·99 | ,, | 0·52 | 3·65 | 7·26 | ,, |
| Baumbach (Germany) . . | 59·28 | 28·63 | 1·29 | ,, | 0·61 | 3·44 | 7·39 | ,, |
| Lodez (Austria) . . . | 66·76 | 20·94 | 1·92 | ,, | 0·81 | 4·64 | 4·43 | ,, |
| Greppin (Germany) . . | 54·99 | 27·91 | 2·54 | 0·05 | 0·83 | 3·67 | 9·87 | ,, |
| Mazeroul (Belgium) . . | 49·64 | 34·78 | 0·46 | 0·19 | 0·41 | 6·42 | 17·78 | Bischof. |
| Crottensee (Austria) . . | 51·32 | 34·28 | 2·98 | 0·30 | 0·24 | 1·63 | 8·50 | Chjzek. |
| Brisan (Austria) . . . | 58·82 | 22·14 | 2·87 | 0·81 | 0·35 | 3·87 | 11·86 | Knaffl. |
| Melnik (Austria) . . . | 40·87 | 36·22 | 2·01 | 2·92 | 1·21 | 4·42 | 12·14 | ,, |
| *Vitrifiable Ferruginous Clays.* | | | | | | | | |
| Olomuczan (Austria) . . | 56·35 | 25·76 | 5·40 | 1·87 | ,, | 2·21 | 7·51 | Knaffl. |
| Tillendorf . . . . | 63·19 | 21·60 | 6·69 | 0·34 | 0·74 | 2·25 | 6·39 | Richter. |
| Stourbridge (England) . . | 45·25 | 28·77 | 7·72 | 0·47 | tr. | tr. | 17·34 | Salvetat. |
| Helingsborg (Sweden) . . | 60·70 | 20·45 | 7·93 | 0·55 | 0·47 | tr. | 9·00 | ,, |
| *Vitrifiable Alkaline Ferruginous Clays.* | | | | | | | | |
| Loeben (Austria) . . . | 58·27 | 23·22 | 5·61 | 2·43 | tr. | 4·12 | 5·89 | Knaffl. |
| Voitsberg (Austria) . . | 54·00 | 20·22 | 5·72 | 1·02 | 0·78 | 7·45 | 10·11 | ,, |
| *Fusible Plastic Ferruginous Clays.* | | | | | | | | |
| Livernon (Lot) . . . | 49·00 | 24·00 | 6·26 | 2·00 | ,, | tr. | 18·00 | Berthier. |
| Vaugirard (Seine) . . . | 51·84 | 26·10 | 4·91 | 2·25 | 0·23 | tr. | 14·58 | Salvetat. |
| Uellnitz (Germany) . . | 50·21 | 17·15 | 7·58 | 5·13 | 6·94 | 1·37 | 11·28 | ,, |
| Moschheim (Germany) . . | 54·28 | 22·47 | 11·42 | tr. | 1·27 | 3·65 | 7·05 | Seger. |
| Chesapeake Creek (U.S.A.) . | 57·00 | 21·50 | 4·31 | ,, | 0·82 | 1·90[3] | 12·84 | Bruno Kerl. |
| Kinkora (U.S.A.) . . . | 57·30 | 17·70 | 6·40 | 0·16 | 0·65 | 1·54 | 13·18 | ,, |
| Stoecken (Germany) . . | 54·01 | 27·98 | 2·10 | 2·85 | 0·65 | 0·68[4] | 11·53 | Fischer. |

[1] Including 4·90 bituminous substance.

[2] Including 2·10 bituminous substance.

[3] Including 1·00 sulphur and 3·80 carbon.

[4] Including 0·56 sulphuric acid.

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| Localities. | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Alkalies. | Body in Firing and Various. | Authors. |
|---|---|---|---|---|---|---|---|---|
| *Fusible Plastic Ferruginous Clays* (contd). | | | | | | | | |
| Kroenningen (Germany) | 57·70 | 27·42 | 6·88 | 5·60 | 0·20 | 0·18[1] | 2·02 | Wimmer. |
| Longport (England) | 54·50 | 16·54[2] | 13·50 | 3·37 | ,, | tr. | 12·00 | Salvetat. |
| Ile Bourbon | 41·87 | 14·29[2] | 27·71 | 0·93 | 0·09 | tr. | 15·75 | ,, |
| Iles Witi | 38·10 | 15·51[2] | 28·49 | 0·85 | tr. | tr. | 16·76 | ,, |
| *Fusible Plastic Calcareous Clays.* | | | | | | | | |
| Lindener Berg (Germany) | 59·91 | 17·96 | 1·09 | 8·21 | 0·40 | 0·41[3] | 12·12 | Fischer. |
| Labischin (Germany) | 46·67 | 13·06 | 5·15 | 11·46 | 4·08 | 4·02 | 15·10 | Michaelis. |
| Schwartz (Germany) | 41·37 | 16·42 | 5·22 | 13·60 | 4·64 | 1·48 | 17·97 | ,, |
| Ecouen (Seine-et-Oise) | 52·23 | 14·52 | 5·00 | 12·04 | 1·75 | 1·91 | 12·55 | Bourry. |
| Velten (Germany) | 47·86 | 11·19 | 5·18 | 14·96 | 1·71 | 3·66[1] | 11·08 | Seger. |
| Chambray (near Tours) | 49·72 | 29·35 | 3·09 | 9·08 | 0·50 | 0·22 | 9·34 | Salvetat. |
| Constance (Germany) | 42·16 | 12·42 | 4·56 | 16·86 | 2·59 | 3·78 | 17·81 | ,, |
| *Fusible Silicious Ferruginous Clays.* | | | | | | | | |
| Villiers-le-Bel (Seine-et-Oise) | 74·83 | 12·29 | 4·88 | tr. | 1·96 | 2·44 | 3·60 | Bourry. |
| Schwartzhutte (Germany) | 77·44 | 9·82 | 5·34 | ,, | 1·36 | 3·87 | 2·48 | Seger. |
| Gieszmansdorf (Germany) | 59·21 | 11·51 | 6·80 | 8·41 | 1·77 | 1·77 | 10·68 | ,, |
| Bockholm (Germany) | 70·22 | 13·67 | 6·80 | ,, | 1·30 | 3·37 | 5·30 | ,, |
| *Fusible Silicious Calcareous Clays.* | | | | | | | | |
| Eberswalde (Germany) | 71·69 | 7·72 | 3·25 | 5·88 | 1·23 | 3·34 | 6·80 | ,, |
| Villiers-le-Bel (Seine-et-Oise) | 68·53 | 8·21 | 4·10 | 8·42 | 0·70 | 1·69 | 8·35 | Bourry. |
| Schwartz (Germany) | 43·37 | 9·31 | 2·84 | 16·65 | 6·00 | 0·98 | 21·00 | Seger. |
| Le Havre | 54·17 | 5·27 | 2·09 | 17·91 | 1·28 | 1·89 | 17·27 | Bourry. |

[1] The proportion of water seems abnormal.
[2] These clays give stoneware (= *donnent des grès*) at a relatively low temperature.
[3] Including 0·40 sulphuric acid.

## 2. Various Raw Materials.

**34. Classification.**—Materials other than clay and water which can enter into the formation of ceramic bodies are divided into five classes, according to the object required in using them:—

(*a*) Materials analogous to clay which can be substituted for it either entirely or in part.

(*b*) Agglomerative and agglutinative materials intended to remedy a lack of plasticity in the body.

(*c*) Opening materials for diminishing the plasticity.

(*d*) Fusible materials for increasing the fusibility.

(*e*) Refractory materials intended, on the other hand, to diminish this fusibility.

### (*a*) *Materials analogous to Clay.*

**35.** Clays can be replaced, entirely or in part, by other hydrosilicates of alumina, which also possess a certain amount of plasticity, and harden similarly under the influence of heat. According to the researches of M. Le Chatelier it seems evident, however, that the majority of these minerals are not true silicates, but kaolinite mixed with hydrates of silica or of alumina. The following are a few details on some of those minerals which have been used in ceramics.

Halloysite is a white oily material, plastic, having a great deal of analogy with kaolins. Its composition is very variable according to the places of production, as the following analyses will show. The first is given by Brongniart, the second by Bruno Kerl:—

| | | |
|---|---|---|
| Silica | 39·90 | 44·94 |
| Alumina | 24·00 | 39·06 |
| Water | 26·00 | 16·00 |

On the other hand, the following is the composition of halloysite of Breteuil (Eure):—

| | |
|---|---|
| Silica | 41·30 |
| Alumina | 47·80 |
| Oxide of Iron | traces |
| Lime | 0·84 |
| Alkalies | 0·76 |
| Water | 9·30 |

Halloysite has often been employed, but without great success, in the manufacture of porcelain.

Lenzenite, a substance rather similar to the preceding, is found at Vilate (Haute-Vienne) and at Call in the Eifel.

It is used sometimes instead of refractory clays, although it is not particularly infusible. Below are two compositions given by Brongniart and Bruno Kerl respectively:—

| | | |
|---|---|---|
| Silica | 27·00 | 30·00 |
| Alumina | 37·00 | 36·00 |
| Oxide of Iron | — | 1·95 |
| Magnesia | — | 0·18 |
| Alkalies | — | 0·50 |
| Water | 25·00 | 21·50 |

Collyrite and allophane contain, according to M. Le Chatelier, the same silicate of alumina, probably $SiO^2$, $Al^2O^3$, $nHO$; the

first extracted at Saint-Sever (Landes). According to Brongniart it has the following composition:—

| | |
|---|---|
| Silica | 59·00 |
| Alumina | 22·00 |
| Water | 26·00 |

According to the researches of M. Vogt, allophane is found mixed with kaolinite in certain clays. It is found in a pure condition at Saint-Antoine (Oise) and in Utah (United States).

Cimolite is a friable stone, more silicious than the preceding minerals, having the formula $4SiO^2$, $Al^2O^3$, $n$HO. It is met with in some of the islands of the Greek Archipelago, and particularly that of Cimolus (Argentiera), where it is used in the body of certain pieces of pottery. According to Klaproth its composition is as follows:—

| | |
|---|---|
| Silica | 93·00 |
| Alumina | 23·00 |
| Oxide of iron | 1·00 |
| Water | 12·00 |

In bodies magnesia plays a part which, from some points of view, corresponds with that of alumina. Hydrosilicates of magnesia can sometimes, at least, partially replace hydrosilicates of alumina.

Among the former are talc and magnesite. Talc or steatite is found in the form of soft friable rock, of slight plasticity. In a pure state it is represented by the formula $4MgO$, $5SiO^2$, $n$HO, but its composition varies according to its place of origin.

| | |
|---|---|
| Silica | 61·75 to 63·00 |
| Magnesia | 31·65 to 36·60 |
| Oxide of iron | — to 2·00 |
| Water | 2·00 to 4·90 |

Talc has been employed in Northern Italy and in the Canton of Grisons for the manufacture of large ceramic vases. It has also been used in Corsica and Egypt.

Magnesite has been used in Spain for the manufacture of porcelain. It was found at Vallecas, near Madrid, and composed of—

| | |
|---|---|
| Silica | 54·00 |
| Magnesite | 24·00 |
| Water | 20·00 |

Marls have sometimes been used in the place of clay for the

manufacture of common potteries. Now they are only used as fluxing materials, and it is under this heading that they will be mentioned later on.

Finally, we may note giobertite, or magnesium carbonate, always mixed with a little silicate, which has been used as a refractory material, and in Piedmont for the manufacture of porcelain ware, and finally, amianthus, which has of late been mixed with certain bodies because of its fibrous texture, for the purpose of giving a certain amount of cohesion. Amianthus is an anhydrous silicate of magnesia, of lime and oxide of iron, the composition of which is rather variable:—

| | |
|---|---|
| Silica | 52·00 to 61·00 |
| Oxide of iron | 2·00 to 20·00 |
| Lime | 1·00 to 17·00 |
| Magnesia | 8·00 to 32·00 |

### (*b*) *Agglomerative and Agglutinative Materials.*

**36.** In the manufacture of refractory wares, particularly of those in silica, which should be obtained as pure as possible, clay has sometimes been replaced by an agglomerant taking possession of and giving a sufficient hardness to the body to allow it to be placed in the oven and then fired at a high temperature.

For this purpose the following have been employed: lime, earthy oxide of iron, calcium and magnesium chlorides, alum, and potassium or sodium silicates. Further details on this subject will be found in the chapter on refractory ware.

When the body is not sufficiently plastic to bear shaping, and when, on the other hand, its chemical composition cannot be modified, it is attempted to give it artificial plasticity by adding to the water of formation some substances which render it viscous, disappear afterwards at the firing and serve as agglutinants.

For this purpose glue, gum, lichen, dextrine, soap, sugar, molasses, and, for very ordinary wares, tar can be used according to the nature of the body and the ware required.

Agglutinative materials have been largely used for the manufacture of French soft porcelain; it is used with a mixture of black soap and parchment glue, also with gum in the black soap.

Now dextrine is employed for the manufacture of porcelain flowers. The difficulty consists in discovering for fine products a sufficiently viscous substance which, after firing, does not leave a carbonaceous residue, and which, for coarse ware, is fairly economical.

### (c) *Non-Plastic or Opening Materials.*

**37. Use and Nomenclature.**—In order to give to ceramic bodies the plasticity needful for the mode of working adopted, and to reduce the shrinkage, clays must often be mixed with anti-plastic materials, that is to say—to employ a technical term—they must be "opened". From this point of view a lean clay is an open one in relation to a fat clay. Thus, in the manufacture of fired bodies, silicious clays are often used to open the plastic clays.

The non-plastic materials properly so called are divided into four classes:—

1. Silicious and sandy substances.
2. Calcareous substances.
3. Carbonaceous substances.
4. Pulverised fired bodies, called grog or rough stuff or grit.

**38. Silicious Materials.**—Silica under all its forms plays a very important part in ceramics—the chief one after clay. Not only does it serve as an opening material, but, as will be seen, it acts either as a refractory material or as a flux, and is indispensable in obtaining the chemical composition required for pottery ware covered with certain kinds of glaze.

Silica presents itself in two different forms, crystalline silica and amorphous silica, or, at least, the grains are sufficiently small to make it difficult to recognise a crystalline form in it.

Crystalline silica has a specific weight of 2·6 to 2·7; it is not easily influenced by alkalies. In Nature it is met with quite pure in the form of rock crystal, almost pure in amethyst, chalcedony, quartz and silex, and more or less mixed with other materials in sands.

Amorphous silica has a specific weight of 2·2 to 2·3; it combines very easily with alkalies, and shows itself in this form no matter what silicate is decomposed; it is therefore in this state

that it is found after the dehydration of hydrosilicate of alumina. In Nature it is found disunited in opal, in infusorial earth, etc.

Crystalline silica is transformed into amorphous silica when it is combined with bases. This combination can take place at a low temperature with potassium and sodium; it is produced at the temperature of the firing of ceramic ware with alumina, lime, magnesia, oxide of iron. A high temperature also at length causes this transformation. In subjecting quartz several times, and for twenty to twenty-four hours each time, to the temperature of hard porcelain heat, the gradual progress of the transformation of crystallised silica to amorphous silica can be traced (Seger).

| | Density. | Proportion of Amorphous Silica. |
|---|---|---|
| Crystallised Silica | 2·662 | — |
| One firing | 2·593 | 41·16 |
| Five firings | 2·501 | — |
| Ten firings | 2·398 | 70·01 |

This change in density has consequently a corresponding modification in volume. For an equal weight amorphous silica occupies a volume 16 to 17 per cent. greater than crystallised silica. This observation has considerable importance in the manufacture of certain silicious ceramic wares. It explains the swelling and the destruction in firing of strongly quartzy wares and the absence of shrinkage of certain refractory wares in which the shrinkage of the silicate of alumina is compensated by the increase of volume of the silica.

In ceramic industries silica is used as an opening substance in the form of quartzy silex and gravel. Under other forms it serves more particularly as a refractory material, and will be mentioned with the substances of that class.

Quartz is found in the form of rock, granite, gneiss, mica-schist, but it cannot be extracted from these economically, and it is collected where Nature herself has separated these rocks into their component parts. Thus it is found in the erratic blocks in the neighbourhood of Saarbrück, or in the pebbles washed by certain rivers (pebbles of the Rhine).

Before introducing quartz into bodies, it must first of all be pulverised. This pulverisation is usually preceded by a firing, which has the double advantage of transforming a part of the

quartz into amorphous silica, that is to say, diminishing the injurious effect of its subsequent swelling, and afterwards of rendering the stone more friable and more easy to pound.

Silex is found in the form of pebbles, black or red, weighing from a few grammes to several pounds, in plots of ground of cretaceous formation. They can either be extracted directly or gathered on the sea shore, at the mouth of certain rivers, where the tides are constantly disaggregating the chalk cliffs.

It is thus found in the mouth of the Thames; but the most important place of exploitation is in the mouth of the Somme, where, over a length of more than 12½ miles and a width of from 10 to 1,650 feet, they form an inexhaustible bed, fed without ceasing by fresh deposits.

These pieces of silex are heated in furnaces analogous to lime furnaces, then thrown into water and reduced to powder. Heat causes them to lose their colour, which has been due to organic substances. Pulverisation takes place either in a dry state in pulverisers covered with porcelain or stoneware to avoid the mingling of pieces of iron, or by a humid method in grinding mills. The first process, a little more costly, produces the more valuable wares. This industry was formerly carried on solely at Runcorn and Newcastle-on-Tyne (England), now the pebbles are similarly treated at Saint-Valery-sur-Somme. Quartz, and especially silex, are only used as opening substances in the manufacture of fine pottery ware, particularly of faience.

**39. Sands.**—Sand is necessarily composed of quartz mixed with varying proportions of feldspar, mica, oxide of iron, carbonate of lime or clay. When the proportion of these materials does not reach two or three per cent., the sand is said to be quartzy; it is feldspathic, micaceous, ferruginous, calcareous or clayey, whenever any one of these substances enters in greater proportion.

Quartzy sand is pre-eminently an opening substance; it presents itself in the form of grains more or less fine, round or sharp-edged. Since their size influences the quality of the ware, both from the point of view of plasticity and fusibility, this influence will be considered in the following chapter. But, as a general rule, sharp-edged sand grains are preferred to round; that is to say,

"quarry" sand to "river" gravels. In fact, the former mingles better with the clayey matrix and adheres more strongly to it.

Some quarries yield quartzy sand, which is naturally very pure, others necessitate the sand first being washed.

Feldspathic and micaceous sands introduce into the body, at the same time as quartz, alkalies which act as fluxes. From the point of view of plasticity and cohesion, grains of feldspar should be preferred to spangles of mica. When the proportion of mica becomes too considerable, the sand must be rejected. It is true that it is always possible to wash it, for mica, on account of its lamellar form, which causes it to float in water, is easily separated by washing.

Ferruginous sand is very much employed for terra cottas. It has been seen that oxide of iron increases the cohesion and gives hardness to the pottery.

Calcareous sand must only be used when the lime found in it is in an impalpable form. The disaggregating action of the grains of lime has already been noted.

Clayey sand, when the nature of the clay which it contains asserts itself, is an excellent opening substance, although less anti-plastic than pure quartz; it has, on the other hand, the advantage of more readily mingling itself with the clay.

A great number of sands are met with in Nature which belong to two or several of the preceding categories, calcareous ferruginous, calcareous clayey, ferruginous calcareous clayey, etc. Their value, according to the purpose for which they are used, can easily be estimated from the preceding observations. In the rather exceptional cases in which suitable sand cannot be obtained, recourse can be had to washing, which is easily done, and at small expense.

Lastly, there is a class of sands which it is expedient to mistrust, these are saline sands, that is to say, those of which the deposits are formed in salt water. They introduce into pottery ware soluble salts, which produce, sometimes long after firing, efflorescence on the surface.

**40. Calcareous Materials.**—Carbonate of lime, especially in the form of calcareous marl, is sometimes used for the opening of clays. However, the object of this mixture is more generally

to render the body more fusible or to give it a settled composition.

As opening substances, calcareous materials are little to be recommended; besides their relative plasticity, which compels them to be used in large quantities, they are detrimental in introducing into the body water and carbonic acid, which render it porous. Carbonate of lime must necessarily be mixed in the form of impalpable powder, and it is necessary that the temperature of firing should be sufficiently high to cause its decomposition and the formation of calcareous silicates.

**41. Carbonaceous Materials.**—In the manufacture of common fired bodies, carbonaceous materials, of which the carbon disappears during firing, can be used advantageously as opening substances.

For this purpose a great number of substances can be made use of, but it is sufficient to mention coal or coke dust, coal cinders, ashes or iron slag, wood sawdust, straw, débris of lignite, peat, tan, etc.

The objection to the use of all these substances, though in a different degree for each, is that their ashes form with the clay fusible silicates producing specks and hollowing out cells in the fired bodies. Some have calcareous schistous ash which occasions similar defects to the grains of carbonate of lime.

On the other hand, they have the advantage of facilitating drying, diminishing shrinkage, of making the firing uniform and rendering the fired bodies lighter, which is often an advantage commercially.

As examples of pottery made specially with opening substances may be mentioned American light fired bodies (terra cotta lumber) manufactured with sawdust, and water vessels for which porosity is the essential quality. More details on this subject will be found in the articles which deal especially with these kinds of pottery.

**42. Pulverised Fired Bodies called Grog or Rough Stuff or Grit.**—Firing by divesting clays of their plasticity transforms fired bodies into opening materials; for this it is sufficient to pulverise them into grains of varying sizes, according to the purpose desired. In this way grit, more or less coarse, is obtained, which in ceramics is known by the name of grog or rough stuff.

This grog is a powerful opening substance, and of an excellent quality. It has an advantage over quartz in not swelling under heat, and of being able to be pulverised in grains of different sizes, which enables the clay to absorb a greater proportion of opening substances. In fact, it can easily be demonstrated that in the same volume it is possible to introduce a larger quantity of grains of grit of different sizes than grains of uniform size.

Besides its anti-plastic qualities, grog has the advantage of giving a more permeable mass, and of expanding less under the influence of heat than quartz. In consequence, fired bodies which have been opened by this means afford a much greater resistance to abrupt variations of temperature, a quality which is very important for certain refractory wares.

Usually it is sufficient in manufacturing grog to grind fired bodies which have already been used, demolished refractory bricks, débris of saggars, crucibles, etc., for which there is no further use. On the other hand, the loss in firing offers an obstacle of which more than one manufacturer would willingly rid himself.

However, in works which manufacture a large quantity of best refractory wares these sources are insufficient, and some clay is calcined specially. This is afterwards pulverised and employed as an opening material to the same clay which is not calcined. This method is indispensable for the manufacture of very aluminous wares, such as are used in the construction of kilns for certain chemical or metallic industries. The employment of quartz as an opening substance, besides having other disadvantages, would be inadmissible in this case, because it would increase the proportion of silica too much.

From the point of view of plasticity, it would be sufficient to heat the clay to 400° C. in order to render it lean, but generally it is preferable to carry it to a temperature at least equal to that of the firing in order to diminish the shrinkage in firing the ware manufactured with its use.

In grinding, mills which yield a large proportion of round grains must be avoided, for, like quartz, and for the same reasons, sharp-edged grains are always preferable.

### (*d*) *Fusible Materials.*

**43. Use and Nomenclature.**—It is known that clays harden more and more, then become vitrified when raised to a sufficiently high temperature, which varies according to their composition and physical texture.

There is often an advantage in lowering the temperature at which this hardening or this vitrifaction takes place. For fired bodies a less costly firing of more resisting wares can thus be obtained.

For faience wares the expansion of the body can be modified and made to correspond with that of the glaze.

Finally, for stoneware and porcelain ware one can determine vitrifaction of the refractory clays, which enter into the composition of the body, and for the decoration of a palette as much richer as the temperature of vitrifaction will be lower.

From a chemical point of view fluxes are substances which form with the silica of the body multiple silicates, more fusible than silicate of alumina. For this end are used alkalies, potassium and sodium, lime, magnesia, and oxide of iron. To these basic fluxes must be added calcium phosphate, which at the same time acts by means of phosphoric acid and by means of the lime which it contains.

Fluxes are therefore divided into alkaline, calcareous, magnesic, ferric and phosphoric calcareous.

**44. Alkaline Fluxes.**—Alkalies can be introduced into bodies in three different forms:—

(1) In the form of salts, such as are found in vegetable ashes, or as they are produced by the manufacture of chemical productions.

(2) In the form of silicates or artificial borates, that is to say, from classes known in ceramics by the name of frits.

(3) In the form of feldspars and of feldspathic rocks.

Alkaline salts are not employed directly. As a small proportion of them only is necessary to considerably increase their fusibility, their homogeneous mixture with the body is difficult and uncertain. In very coarse pottery ware vegetable ashes have been able to be used. In all cases carbonates are to be

rejected because of the carbonic acid which they give off during firing, with a tendency to inflate the mass. Sulphates are preferable, but besides presenting the other inconveniences which have just been noted, they require, moreover, a high temperature for being decomposed.

Frits, on the contrary, are in constant use in the manufacture of glazes, but they are little used in body mixtures. They will be particularly noted in the article on the manufacture of glazes. It will be sufficient here to say that for bodies, and because of the price, silicious frits are the only ones employed. They are manufactured by fritting together silica and alkaline salts, the glassy substance produced being then finely pulverised.

Instead of manufacturing frits directly, they are sometimes replaced by glass or débris of glass, which is found in the trade.

This flux, because of its low price, can be used in the manufacture of common stoneware. But, as in the case of alkaline salts, it is necessary to make a very careful apportioning and mixture.

Feldspar and feldspathic rocks are the alkaline fluxes which are most used. They are widely distributed in Nature, but are rarely pure enough to be of use. Their natural colour is not a sign of purity. Certain white feldspars become yellow, red or black at a high temperature, while others which are much coloured become white. They are first heated strongly, then reduced to a fine powder, which is the form in which they are found in commerce.

It is known that feldspars are silicates of alumina and of alkalies, potash and soda. They generally contain also a small proportion of oxide of iron, of lime, and of magnesia. In some cases the quantity of lime becomes too important to be neglected. There are a few beds of feldspar in France, in Haute-Vienne and Drôme, but the feldspars of Norway are used in great quantity, and these supply the chief European ceramic factories.

Workable feldspars are also found in the Palatinate, in Bavaria, Silesia, Bohemia, Galicia, Finland, Calabria, and in the States of Maine and Delaware in the United States. The table given further on (pages 80-81) gives the composition of these feldspars.

Among feldspathic rocks pegmatite is the most in use. It is

largely employed in France, where there are the important beds of Saint-Yrieix, and fairly often in England, where it is known by the name of Cornish stone, and is found in Cornwall.

Other analogous rocks have sometimes been utilised, among others being porphyry, trachytes and basalts. Their composition is generally very variable, as will be seen from the table given hereafter.

**45. Calcareous Fluxes.**—Lime is introduced into bodies as a flux in the state of calcium carbonate, sulphate, or silicate.

Carbonate of lime can only be used as a flux when the temperature of firing the pottery is sufficiently high to decompose and eliminate the carbonic acid. At a lower temperature the carbonate only serves as an opening substance. In "mixtures" it must not be forgotten that there are for 100 parts in weight of carbonate, 56 of lime and 44 of carbonic acid.

The beds of carbonate of lime are very numerous. In ceramics débris of white marble, chalk, almost pure carbonates, calcareous heaps and marls are used.

Marls are mixtures of carbonates of lime and hydrosilicate of alumina. According to the researches of MM. Le Chatelier and Vogt, this silicate is not kaolinite, in spite of the opinion generally admitted; it would correspond in reality with the formula $Al^2O^3$, $5SiO^2$, $n$HO.

The composition of marls is very variable, not only according to the localities, but according to the layers of the bed. Calcareous marls containing from 20 per cent. to 40 per cent. of hydrosilicates of alumina are distinguished from clayey marls, in which this proportion reaches 70 per cent. to 80 per cent. They nearly always contain a certain proportion of oxide of iron, which can amount to 7 per cent. or 8 per cent.

Marls are more or less plastic, according to their contents of silicate of alumina, so that, generally speaking, clayey marls may be considered as relatively plastic substances, and calcareous marls as opening substances.

Sulphate of lime can only be used for pottery ware fired at a high temperature, because it is with great difficulty decomposed.

Its only advantage over carbonate of lime is its relative solubility in water, which allows it to be mixed more easily in bodies. But it must not be employed simultaneously with too strong a

CHEMICAL COMPOSITION OF

| Designations. | Silica. | Alumina. |
|---|---|---|
| *Feldspars with Potassium Base.* | | |
| Chanteloube (Haute-Vienne) | 61·00 | 20·56 |
| Bonnefond, near Bourganeuf (Vienne) | 66·00 | 18·81 |
| Cambo (Pyrenees) | 64·00 | 21·02 |
| Orjervi (Finland) | 63·50 | 20·10 |
| Serdobole (Finland) | 64·03 | 18·47 |
| Halle (Saxony) | 62·76 | 19·20 |
| Quabenstein (Bavaria) | 61·37 | 20·23 |
| Aue, near Schneeberg (Germany) | 66·00 | 17·59 |
| Sargadelos (Galicia) | 62·00 | 19·48 |
| Carlsbad (Bohemia) | 64·50 | 19·75 |
| Oporto (Portugal) | 62·06 | 19·61 |
| Newcastle, Delaware (United States) | 62·20 | 19·78 |
| Dixonplace, Wilmington (United States) | 58·70 | 23·95 |
| *Feldspars with Potassium and Sodium Base.* | | |
| Arnage (Drôme) | 64·80 | 22·10 |
| Norway | 64·44 | 18·75 |
| ,, | 64·98 | 19·18 |
| ,, | 65·23 | 18·64 |
| Bischoffteinitz (Germany) | 65·35 | 19·38 |
| Hagendorf, near Weiden (Bavaria) | 64·80 | 19·83 |
| Odenwald (Germany) | 67·92 | 18·90 |
| ,, ,, | 64·40 | 18·91 |
| Arzberg (Fichtelgebirge, Germany) | 70·10 | 17·16 |
| Tirschenreuth (Palatinate) | 64·08 | 21·73 |
| Chotoun, near Prague (Bohemia) | 62·71 | 20·51 |
| ,, ,, ,, | 63·21 | 22·93 |
| *Feldspars with Sodium Base.* | | |
| Chanteloube (Haute-Vienne) | 67·63 | 20·48 |
| Calabria (Italy) | 65·87 | 20·60 |
| *Pegmatites.* | | |
| Saint-Yrieix (Haute-Vienne) | 76·10 | 15·37 |
| ,, ,, | 70·64 | 16·87 |
| Regensburg (Germany) | 87·78 | 7·36 |
| Helston, Cornwall (England) | 74·34 | 18·46 |
| Frossasco (Piedmont) | 71·00 | 18·27 |
| China | 75 to 76 | 13 to 16 |
| *Porphyry* | 68 to 77 | 9 to 15 |
| *Trachytes* | 70 to 79 | 15 to 17 |
| *Basalts* | 33 to 53 | 10 to 18 |

## Feldspars and Feldspathic Rocks.

| Oxide of Iron. | Lime. | Magnesia. | Potash. | Soda. | Loss in Firing. | Authors. |
|---|---|---|---|---|---|---|
| — | 0·38 | — | 14·99 | — | — | Malaguti. |
| — | 0·40 | — | 13·60 | — | 1·16 | ,, |
| 0·17 | 0·20 | tr. | 13·61 | — | 0·20 | Salvetat. |
| tr. | 0·30 | tr. | 16·10 | tr. | — | Laurent. |
| — | 0·67 | 0·18 | 15·24 | — | 1·02 | Malaguti. |
| tr. | 0·46 | 0·18 | 14·90 | — | 1·70 | ,, |
| — | 0·39 | 0·16 | 15·75 | — | 1·31 | ,, |
| — | 0·40 | 0·38 | 15·00 | — | — | ,, |
| tr. | 0·35 | 0·12 | 15·72 | — | 1·64 | ,, |
| 1·75 | tr. | — | 11·50 | — | — | Klaproth. |
| — | 0·38 | 0·16 | 16·07 | — | 1·11 | Malaguti. |
| tr. | 0·58 | 0·50 | 15·14 | — | 1·53 | ,, |
| tr. | 2·09 | 0·31 | 12·64 | — | 1·65 | ,, |
| | | | | | | |
| tr. | — | — | 3·20 | 6·50 | 3·20 | Salvetat. |
| 0·65 | 0·27 | — | 13·82 | 2·40 | — | Bischof. |
| 0·33 | tr. | 0·25 | 12·79 | 2·32 | 0·48 | Seger. |
| 0·47 | 0·12 | 0·21 | 12·57 | 2·45 | 0·23 | Bourry. |
| 0·33 | — | tr. | 11·18 | 3·74 | 0·25 | Seger. |
| 0·22 | — | tr. | 11·63 | 3·23 | 0·67 | ,, |
| 1·28 | 2·02 | 0·39 | 1·87 | 6·93 | 0·60 | Bischof. |
| 0·67 | 0·74 | — | 13·76 | 2·17 | — | ,, |
| 0·91 | 0·45 | 0·98 | 1·52 | 8·65 | — | ,, |
| 0·93 | 0·53 | 0·78 | 1·48 | 10·08 | — | ,, |
| 0·47 | baryta 2·83 | tr. | 9·44 | 4·08 | 0·21 | Seger. |
| 0·45 | 3·62 | tr. | 1·25 | 8·45 | 0·59 | ,, |
| | | | | | | |
| — | 0·65 | — | — | 10·26 | — | Malaguti. |
| tr. | 0·38 | 0·20 | tr. | 11·10 | 1·20 | ,, |
| | | | | | | |
| 0·13 | 0·17 | tr. | 2·84 | 4·58 | 0·40 | Salvetat. |
| 0·73 | 1·31 | 0·20 | 4·22 | 4·97 | 0·34 | Vogt. |
| 0·84 | 0·29 | — | 1·60 | 1·00 | 1·34 | Malaguti. |
| tr. | — | 0·24 | 6·00 | — | 0·96 | ,, |
| tr. | 0·50 | 0·21 | tr. | 9·10 | — | Salvetat. |
| 0 to 0·85 | 0 to 0·40 | tr. | 3 to 3·5 | 2 to 5 | 2 to 4 | Ebelmen and Salvetat. |
| — | 0·2 to 2 | 0·2 to 2 | 3 to 10 | tr. | — | — |
| 1 to 5 | 0·5 to 1·5 | 0·2 to 0·5 | 2 to 8 | 4 to 10 | — | — |
| 2 to 20 | 6 to 15 | 2 to 12 | 2 to 16 | 0·5 to 3 | 0 to 6 | — |

proportion of alkalies, because in that case it can form alkaline sulphates, which are more difficult to decompose than sulphate of lime.

It is well to calcine it before mixing in order to eliminate the considerable proportion of water which it contains. Many mineral forms of sulphate of lime or gypsum contain impurities: clay, oxide of iron, gravel, carbonate of lime, sulphate of strontia.

Silicate of lime proceeds from the slag of blast furnaces. It is composed of silicate of lime and alumina, more frequently mixed with oxide of iron, magnesia, manganese and sulphur in the form of sulphate of sulphide.

These very variable and very impure products are mentioned here because lime constitutes their chief flux. They are used on a fairly large scale for the manufacture of quarries in stoneware or imitation stoneware.

**46. Various Fluxes.**—*Magnesia* can be mixed with bodies either in the form of a double carbonate of lime and magnesia, which constitutes the natural rock known as dolomite, or in the form of silicate of magnesia or of talc. Magnesic fluxes are used for the manufacture of certain porcelain ware, they also sometimes enter into the composition of glazes.

*Ferric Fluxes.*—Oxide of iron only acts as a flux when it is in the form of a protoxide. In the form of sesquioxide its action is similar to that of alumina. It is added directly to bodies only for the purpose of colouring them.

*Phospho-Calcareous Fluxes.*—Phosphate of lime is generally extracted from the bones of animals, but phosphorite can also be made use of.

The bones employed are chiefly those of the ox, and preferably the hard bones of the extremities. (The bones of horses and pigs are rejected because they give colour to the body.) They are dried, cleaned by boiling in water, calcined until they are entirely white, then finally pulverised.

Phosphorite is a natural fibrous stone, found in Estramadura, containing up to 93 per cent. of calcium phosphate. Other less pure varieties are met with at Amberg, in Bavaria.

Phosphate of lime is chiefly, if not exclusively, used in England for the manufacture of soft porcelain.

### (*e*) *Refractory Materials.*

**47.** Only those materials are here dealt with which, mixed with clays, render them less fusible, and not substances which, like lime, magnesia, graphite, can of themselves give refractory productions. The latter will be noted in the chapter devoted to the special manufacture of these wares.

Without for the moment dealing with the complex question of the fusibility of clays, it is sufficient to say that for ordinary clays, which are always silicious, silica is the refractory element, whereas for bodies which are destined to be vitrified (stoneware and porcelain) it is alumina which plays this part.

Silica is generally introduced into bodies in the form of quartz, silex and gravel. These materials have already been studied under anti-plastic substances, and it is not necessary to return to them. But silica has sometimes been used in other forms for the special object of utilising its refractory properties.

Infusorial earth is formed by the débris of seaweed of the diatomic class and not the carapace infusoria, as was believed for a long time. In the undried state its weight is less than one kilogramme per decimetre cube; after drying it is reduced more than one half. Considerable beds of it are met with in Lüneburger Heide (North Germany) and in Hesse. Its composition is given by the following analyses—the two first relate to the upper and lower layers of the beds of Oberohe and the last to a green clay of Neuohe:—

| | | | |
|---|---|---|---|
| Silica | 87·86 | 74·48 | 79·80 |
| Alumina | 0·13 | — | 1·50 |
| Oxide of iron | 0·73 | 0·39 | 2·60 |
| Lime | 0·40 | 0·20 | 0·30 |
| Magnesia | — | 0·20 | 0·40 |
| Water and organic substances | 10·71 | 24·43 | 15·00 |

The composition varies greatly with the beds, but silica is always found in them with a density of 2·2 to 2·3. As in this form it lends itself better to the formation of multiple silicates it is less refractory than quartz. Meanwhile the exceptional lightness of infusorial clam renders it very useful for the manufacture of refractory wares employed for hearths of locomotive or marine boilers.

Gannister is the name given to a grit in England and the United States, which is found underneath the carboniferous formation; it can be used either by itself, or mixed with a refractory clay. The following is its composition :—

| | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Loss in Firing. |
|---|---|---|---|---|---|---|
| Gannister of Sheffield, No. 1 . | 94·10 | 4·21 | 0·70 | tr. | tr. | 0·69 |
| ,, ,, ,, No. 2 . | 95·55 | 4·85 | 0·85 | 1·13 | 0·11 | 0·41 |
| ,, of Wales . . . | 93·05 | 4·23 | 0·80 | 0·26 | 0·26 | 1·00 |
| ,, of Indianapolis, U.S.A. | 98·43 | 0·60 | 0·57 | — | — | 0·29 |

Gaize is a porous rock, light, composed of more than 80 per cent. silica, half of which is in an amorphous form of alumina, oxide of iron, lime and magnesia. For the rest its composition is rather variable. It forms a geological layer in the cretaceous pieces of ground between the gault clay and glauconous chalk. It crops out in France at different points in the Ardennes and Oise. It can be used mixed with refractory clay.

Bamboo sugar is extracted from the plant, more particularly in the Island of Java, whence it is sent to China and used in the manufacture of porcelain. Its composition is as follows :—

| | |
|---|---|
| Amorphous silica . . . . . | 86·4 |
| Oxide of iron . . . . . | 0·4 |
| Lime . . . . . | 0·3 |
| Potash . . . . . | 4·8 |
| Organic substances . . . . . | 0·5 |
| Water . . . . . | 7·6 |

The bamboo of South America contains a much greater quantity of potassium, and would become a flux.

Alumina can be introduced into bodies in the form of hydrosilicates of alumina, more aluminous than kaolinite, which have been previously mentioned. But there exist other hydrosilicates of alumina which are not plastic, which are met with in Nature, and are fairly often used in ceramics because of their high contents of alumina. These are bauxites, rocks of very variable composition, often mixed with strong proportions of oxide of iron. As regards their refractory qualities the best bauxites are naturally the least ferruginous. But those also can be used, the contents of which contain a medium quantity of oxide of iron, on condition that they are subjected to a high temperature before being pulverised.

There are numerous beds of bauxites in the departments of

Bouches-du-Rhône, Hérault, Var, Vaucluse and Charente. They are also found in Ireland, near Belfast, in Carniola, Croatia, Styria, in Germany, in the Province of Nassau, in Calabria and in Senegal.

Below is the composition of some bauxites which are specially useful in ceramics, the three first from Veyrac (Hérault), the fourth from Croatia, the two last from Feistritz (Styria):—

| | | | | | | |
|---|---|---|---|---|---|---|
| Alumina . | 70·38 | 68·50 | 64·84 | 56·82 | 64·60 | 54·10 |
| Silica . . | 9·00 | 10·40 | 14·98 | 11·28 | 7·50 | 12·00 |
| Oxide of iron | 5·20 | 3·44 | 5·38 | 1·60 | 2·00 | 10·40 |
| Water . . | 15·59 | 21·10 | 14·80 | 24·20 | 24·70 | 21·90 |

## 3. Trials of Raw Materials.

### (*a*) *Trials of Clays.*

**48. Methods of Trial.**—The trials to which clays can be subjected are of two kinds: chemical trials, and physical or mechanical trials.

The object of chemical trials is the determination of the composition of clays. According to this class of ideas three different objects can be proposed corresponding to the distinct methods of analysis:—

(1) The constitution of the clay can be investigated, that is to say, the determination of the nature and composition of the natural mineral substances which by their mixture have formed the clay.

(2) It can also be proposed to discover the chemical "global" composition without being concerned with the form in which the various simple substances disclosed by analysis are combined.

(3) Finally, the object can be simply to find out if, and in what proportion, a certain substance is found in the clay.

The object of physical or mechanical trials is to determine the chief physical properties either in an absolute manner or by comparison. The trials which can be made in this respect are three in number:—

(1) Trials in view of determining the texture of the clay, and particularly the coarseness of the grains which constitute it.

(2) Trials on its plasticity and on its shrinkage during drying.

(3) Trials on its fusibility, its porosity and its shrinkage at different temperatures.

**49. Trials on the Constitution of Clays.** — If the minerals which enter into the constitution of a clay, as well as the form and proportion in which they are found in it, could be determined exactly by sufficiently simple and precise methods, all the properties of the clay would be able to be deduced therefrom without it being necessary to have recourse to other trials. Unfortunately, however, this is not the case, and trials on the constitution of clays have still the character of scientific researches, and are but little accessible in the daily practice of ceramics.

The employment of grinding for the separation of pure clay from other substances mixed with it has been much praised. But as from the commencement the primary difficulty is met with of knowing to what point grinding shall be carried on, it is compulsory to admit that all grains not having $\frac{1}{100}$th of a millimetre of side shall be considered as clay. But this is an hypothesis which cannot be justified, since, as has been previously noted, the majority of materials mixed with clay, silica, alumina, lime, oxide of iron, can be found in the form of a sufficiently impalpable powder which cannot be separated from hydrosilicate of alumina by any mechanical process. It is well then only to consider grinding as a means of determining the texture of the clay, and not as a method of analysis.

In the present state of chemistry the best processes by which information on the constitution of clay can be arrived at consists in submitting it to the action of sulphuric acid, first diluted, then concentrated. In subjecting a clay reduced to as impalpable a powder as possible in a capsule of porcelain, or a platina crucible, for several hours at a temperature of about 100°, to the action of sulphuric acid, diluted in five or six times its volume of distilled water, carbonates of lime and magnesia, hydrated oxide of iron, etc., are dissolved in this liquid, and these can be separated according to the general methods. The residuum, after being duly filtered, washed and dried, comprises silicates and quartz. It is then placed in a platina crucible, and, at a temperature of 300° C., subjected for fifteen to twenty hours to the action of concentrated sulphuric acid. The hydrosilicates of alumina as well as the powdered mica are attacked

and dissolved, and the residuum is composed of quartz, coarse mica, and feldspar. It is well to repeat the operation a second time to see if it produces a fresh attack, and if the residuum diminishes in weight. In this latter case it is necessary to begin a third operation until the weight remains constant. Thus, on the one hand, the weight of hydrosilicates of alumina and of powdered mica is obtained, and on the other that of quartz, feldspar and coarse mica.

There is no process for the separation of hydrosilicates of alumina from mica, and one must be content with analysing the mixture; then the composition of mica being supposed known (potassic mica, muscovite), the estimation of silica and of alumina, corresponding to the contents in alkalies, is allotted. The remainder is attributed to hydrosilicates of alumina. Generally, if this process has been well carried out, the proportion of silica and of alumina thus found ought to correspond with the formula of the kaolinite. If such be not the case, and if a fresh trial give the same results, it would be necessary to conclude that there are, besides kaolinite, other silicates of alumina. It would then be necessary to have recourse to the method proposed by M. Le Chatelier, and employed by M. Vogt in his researches on the constitution of clays, a method which will be dealt with later.

Regarding the residuum from the attack by concentrated sulphuric acid, composed, as has been said, of quartz, feldspar, coarse mica, the last can be separated by washing, because, on account of its lamellar form, it remains for a longer time in suspension in water. Therefore a mixture of quartz and feldspar is obtained which it is impossible to separate. As previously, an analysis of it could be arrived at by supposing the composition of feldspar known (nearly always orthose), and then attributing to it the proportion of silica corresponding to the weight of alkalies and of alumina; the silica remaining will be considered as being due to quartz.

The determination of the quantity of water evaporated by heating a clay to increasing temperatures can also give some information as to its constitution. In heating a clay to 120° up to the point when two successive weighings indicate no diminution of weight, a global weight is obtained which includes hygrometric

water, the water from the hydrates of silica, oxide of iron and the volatile parts of organic substances. If this same clay is then left for about ten days under an inverted glass vessel in a humid atmosphere, the increase of weight which it will evince will indicate the proportion of hygrometric water alone.

On the other hand, by heating in contact with air for a fairly long time, at a temperature from 600° to 700°, clay which has been dried at 120°, the fresh diminution of weight which will be observed corresponds to the water of the hydrosilicate of alumina, hydrate of alumina, and to the carbon of organic materials. By carrying on the same operation in a crucible hermetically sealed, or better, in a tube traversed by a current of carbonic acid, combustion of the carbon is prevented, the weight of which can then be obtained by observing the difference. The temperature must not be raised above 700°, or decomposition of carbonates would take place.

Finally, referring to the different hydrosilicates of alumina, M. Le Chatelier has demonstrated that all these lose their water of hydration between 400° and 700°, with the exception of allophane and collyrite, which dehydrate at 120°. This observation has enabled M. Vogt to demonstrate the presence of allophane in certain clays.

**50. Chemical Analysis.**—Although, as has been seen, the preceding trials necessitate clever experimenters in order to be carried through properly, the "global" chemical analysis of a clay can, on the contrary, be made by any one accustomed to chemical manipulation. The following is the method most used:—

One or two grammes of clay powder, dried at 120°, as it has been previously noted, are taken and mixed with five or six times their weight of carbonate of soda, which has been previously melted and pulverised, then the whole is placed in a platina crucible, which is heated up to the complete fusion of the mixture. After cooling, the crucible is placed in a capsule and distilled water added, then, drop by drop, some hydrochloric acid until all bubbling has ceased. Then the crucible is taken away, it is washed, the water used for the washing being turned into the capsule, then the latter is heated slowly, so that all the water is evaporated and the solid residuum is maintained for two

hours at about 100°. Hydrochloric acid is again added, and the mixture is heated up to ebullition, then the liquid is poured on to a filter paper. The silica settles while the bases travel about in the form of soluble chlorides. The filter is dried, then calcined, the weight of the ashes, diminished by those of the paper, gives the weight of the silica contained in the tested material. To confirm this it is well to dissolve with heat this silica in carbonate of soda to see if dissolution takes place without residuum. If this is not the case analysis must be made again, since the attack of clay by carbonate of soda has not been complete.

The liquid which has traversed the filter is divided into two equal parts after having been diluted with water.

Into the first ammonia is poured until the liquid becomes alkaline, it forms a precipitate of alumina and oxide of iron which is allowed to remain for several hours.

Then it is poured on a filter, is washed carefully with warm water, then the filter is dried, calcined and weighed. The weight obtained is that of the alumina and of the oxide of iron.

The filtered liquid is heated until its volume is reduced by one half, then treated by an excess of warm oxalate of ammonia. It forms a precipitate of oxalate of lime which is filtered, washed, dried, and calcined to redness, then rapidly weighed, so as to estimate the lime in the form of caustic lime.

Lastly the filtered liquid is treated by a solution of phosphate of soda. Magnesia is precipitated in the form of ammonium magnesium phosphate, filtered, dried and calcined, and thus estimated in the form of pyro-phosphate of magnesia.

The second part of the liquid preserved after the elimination of silica is employed for the determination of the oxide of iron. For this end one begins to turn all oxides of iron into protoxides by placing the liquid, which is freely acid, in a capsule, by boiling it, and adding small pieces of pure zinc until the liquid, from being a yellow colour, becomes colourless. Then a solution of permanganate of potash is poured on it, drop by drop, and this remains discoloured so long as there is any iron in the form of protoxide. Directly the iron becomes transformed into peroxide the liquid assumes a pink tint. It is

sufficient to read the volume of the liquid so used to deduce from it the weight of the oxide of iron contained in the piece, and, by difference, that of the alumina. It is well, from time to time, to verify the liquid named by dissolving a known weight of pure iron in hydrochloric acid.

When it is desired to determine the alkalies, which ought always to be done by careful analysis, very finely pulverised clay is placed in a platina capsule mixed with fluorhydrate of ammonia. After some hours of heating, sulphuric acid is added, and it is evaporated to dryness. All the bases are then in the form of sulphates; they are dissolved in warm water, and, if the operation has been well carried out, no residuum should remain. In treating this solution with baryta water, alumina, oxide of iron, lime and magnesia are precipitated at the same time that it deposits sulphate of baryta. It is filtered, carbonate of ammonia is added to the liquid, it is again filtered, then the liquid is evaporated, calcined lightly to volatilise the ammonia salts. Then it is taken up again with water, and the same treatment is re-commenced with carbonate of ammonia in order to bring about the precipitation of the earthy bases. After fresh evaporation and a slight calcination alkalies are added, estimated in the form of carbonates. Calcining can also be carried on in the presence of sulphuric acid, and the estimation made in the form of sulphate.

In ordinary analysis there is no advantage in estimating potash and soda separately. If, however, any one wishes to make this determination, the alkaline carbonates would be taken up by acidulated water, and heating would be carried on slowly up to drying, after having added some bichloride of platinum.

**51. Special Estimation.**—Special estimations are employed when it is simply desired to know if, and in what proportion, a certain substance exists in the clay.

The most simple of these estimations is that of hygrometric water, the content of which can be fairly variable with the same clay, so that sometimes account must be taken of these differences. It has been seen that this estimation is accomplished by merely heating to 120° a given weight of powdered clay until two consecutive weighings show no further diminution.

It is often very important to know whether a clay contains any oxide of iron, and in what proportion it is found therein. This investigation can be made without difficulty by taking 50 grammes of finely-powdered clay, and subjecting it to sulphuric acid diluted with two to three times its volume of water. After having allowed the mixture to remain for twenty-four hours, it is diluted with water and filtered. The liquid thus obtained is placed in a capsule and heated, some pieces of pure zinc being added at the same time. All the iron is brought back to the state of protoxide, and, as has been previously said, it is treated by a solution of permanganate of potash. If it acts simply by confirming the presence of iron without estimating it, the clear liquid is poured off gently after the attack of sulphuric acid and an excess of ammonia is added; if there is some iron in the clay, a brown precipitate is formed in the case of peroxide, and a precipitate which turns brown in contact with the air if the iron is in the form of protoxide.

Lime is also a substance which it is important to recognise in clays, especially when it exists in the form of a carbonate. This is done very simply by pouring an acid (sulphuric, hydrochloric, nitric, etc.) on the clay. If it produces an effervescence due to the evolution of carbonic acid, this is a proof that the clay contains some lime, and its proportion can be roughly estimated according to the intensity of the effervescence. In order to make a careful estimate, an analysis, such as has been previously indicated, must be resorted to. For fairly calcareous clays the following process can also be employed: In a light glass are placed 10 grammes of powdered clay, and this is diluted in water and the mixture stirred; into a second glass, which must also be light, are poured about 10 grammes of acid, which is diluted with from two to three times its volume of water. The two glasses are then placed on the pans of a balance and weighed. Then the contents of the second glass are poured into the first, drop by drop, very slowly, so as to avoid a strong effervescence or a considerable heating of the liquid. When the ebullition has ceased the glass is shaken in order to force the bubbles of carbonic acid, which have been able to remain in the clay, to evolve. The two glasses are replaced on the pan, the difference of weight, which indicates the proportion of carbonic acid contained in the clay, is determined, and the lime contents are

deduced from this. Of course if the clay contains organic substances, this process is not applicable. The proportion of soluble salts contained in a clay can be easily determined by treating a certain quantity of clay (half to one ounce) for one hour in boiling distilled water. The mixture is poured on a filter, then the filtrate is evaporated to dryness, and the residuum weighed. It can be analysed according to the general methods.

52. **Trials of the Texture.**—It has been seen that clays are formed of extremely thin lamellar grains of hydrosilicate of alumina mixed with other grains, very variable in size, depending on the nature and proportion of the other materials entering into the composition of the clay. It would, therefore, seem that a minute microscopic examination would enable one to determine the intimate constitution of a clay, and, consequently, its properties. Unfortunately, this kind of investigation presents considerable difficulties, which only few experimenters versed in micrography have been able partially to overcome. In ceramic practice the microscope only enables one to recognise the form and often the nature of the coarsest grains, consequently it only affords indications which are absolutely insufficient. One must be content to determine the proportion of grains of different sizes which the clay contains by examining the largest under a microscope or with a strong magnifying glass.

The separation of grains according to their size could be effected with a sieve, but the finest of these would be still too coarse and would give incomplete results; it is much better then to have recourse to grinding. This can be done in two ways: A clay reduced to powder can be placed in suspension in water with a strong agitation, then left to settle. The coarsest grains are precipitated rapidly, then the medium sized, and finally the finest parts remain for a long time in suspension, and do not settle for several hours, or even for several days. If the process is carried on in a graduated test glass, the number of divisions can be read which correspond to each size of grain.

This method is very simple, but the results arrived at are inexact, because the particles which are at the bottom of the test glass at the moment of agitation remain mixed with the coarser grains. Moreover, the reading of the divisions is neces-

sarily left to the approximation of the experimenter. It is therefore better to have recourse to the second method, which is more complicated, but more precise. It consists in submitting the clay reduced to powder to a continuous current of water, the swiftness of which can be regulated at will. It is understood that with a reduced speed only the finest particles are removed, then with greater speed the medium sized particles.

Different apparatus have been constructed on this principle. Fig. 1 represents the apparatus proposed by M. Schulz. The clay is put into a glass into which water runs from a high

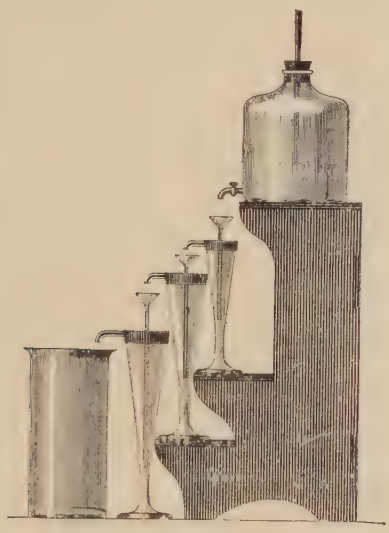

Fig. 1.—Schulz Levigating Apparatus.

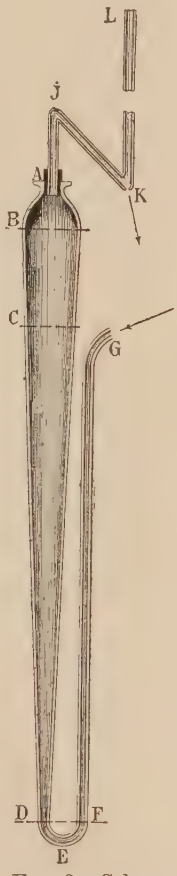


Fig. 2.—Schone Levigating Apparatus.

reservoir, the speed being regulated to draw all the grains except the coarsest. The removed particles are brought into a second glass, which has a larger diameter, and where, consequently, the speed of the current diminishes and allows the largest grains brought down to settle. The same takes place in a third glass, larger than the second, and finally only the finest particles reach the lowest reservoir, where they settle. At the end of the operation it is sufficient to weigh the dried residuum contained in the different glasses.

The apparatus shown in Fig. 2, invented by M. Schone, gives a more approximate solution of the problem. It consists of a

conical tube, A D, the height of which is from 23½ to 25½ inches, the diameter at B 1·97 inch, being reduced to 0·20 of an inch for the funnels D G and A L. The clay to be tested is first diluted in water, then the mixture is poured into the tube A D, by the opening A, from which the india-rubber stopper is removed. Water is added until the liquid reaches the mark C. After having reunited the stopper with the tube A L, a current of water is made to pass which enters at G and makes its exit by a small orifice, K. The speed of this current is measured by the pesometric height which the water takes in the tube K L, to which is given a height of about 59·06 inches, and which is graduated to escape by the opening, K. The entry of the water being regulated by a tap, it is arranged that the level of the water rises, *e.g.*, from 0·71 inch in K L, the current produced taking away the grains of less than ·0039 inch, which are collected in a receiver placed under the orifice K. When the water which flows has become clear the speed is increased, the grains removed are brought into a second receiver, and the operation is thus pursued until the greatest speed is reached which the current can obtain by this apparatus, the particles then remaining in the tube being at least ·0156 inch. The deposits in the various recipients are dried and weighed as formerly. In order that the orifice K may not be choked up, it is necessary to first sift the diluted clay in a sieve of 0·78 inch mesh.

According to Seger the different sizes of grains can be classified as follows:—

Grains of less than ·00039 inch considered as clay.

Grains of ·00039 to ·00098 inch showing a certain amount of plasticity when held between the fingers, but yielding a mass which disaggregates on drying.

Grains from ·00098 to ·00156 inch having no more plasticity, but the grains of which are not susceptible to the touch.

Grains from ·00156 to ·0118 inch, which form fine sand.

And grains above ·0118 inch, or coarse sand. The following table of tests, made by Seger on four different clays, is given to show the results which can be obtained by levigation:—

| | No. 1. | No. 2. | No. 3. | No. 4. |
|---|---|---|---|---|
| Grains of less than ·00039 in. . . . | 82·18 | 37·10 | 68·32 | 62·00 |
| ,, ·00039 in. to ·00098 in. . . | 11·16 | 20·24 | 10·88 | 2·14 |
| ,, ·00098 in. to ·00156 in. . . | 3·52 | 13·84 | 9·08 | 1·84 |
| ,, ·00156 in. to ·0118 in. . . | 3·00 | 28·46 | 10·64 | 11·58 |
| ,, more than ·0118 in. . . | 0·58 | 0·34 | 0·18 | 21·20 |

The first clay can be considered as the type of plastic clays, and the fourth as that of silicious clays, numbers 2 and 3 representing intermediary clays. When carried out with precision, levigation can give useful information and explain the singularities which certain clays evince during drying.

**53. Trials of the Plasticity.**—The plasticity of a clay depends on three things:—

(1) On the plasticity of the hydrosilicate of alumina which it contains.

(2) On the proportion of this body relatively to other materials.

(3) On the nature, the size, and the form of the grains of these materials.

This observation is sufficient to show that neither chemical analysis, nor the proportion of alumina, nor the quantity of hygrometric water, nor the tests made by levigation can serve, as has been proposed, as a measure of plasticity. It is necessary to have recourse to direct mechanical tests. The most simple and almost the only one in use consists in moulding the clay in the hand, and estimating the plasticity by the touch. However primitive this means may be, it must be confessed that it is nearly always sufficient for ceramic purposes. However, to facilitate the comparison of clays among themselves, the following process, indicated by M. Bischof, can be recommended.

A certain quantity of clay reduced to powder is dried at 120°, and is divided into several parts, all having the same weight, 50 grammes for example. On the other hand, a quartzy, fine, dry sand is taken, and to each part of clay is added a given increasing quantity of it.

An intimate mixture is made, water is added to form a body which can easily be shaped by hand, and a series of pellets are fashioned, which are left to dry. When the drying is complete these pellets, which are placed above a piece of white paper, are

rubbed with the thumbs, and it is noted if this rubbing disintegrates the dry body. If the proportions of sand have been suitable, the pellets which have the least of it remain intact, those which have the most are completely disintegrated, and an intermediary is found which forms the limit, only permitting at rubbing a small quantity of grains to be detached. The proportion of sand which it contained serves to measure the plasticity.

M. Bischof desired to render this process more precise by employing mechanical arrangements to effect the rubbing, but it does not seem that this complication is to be recommended in the employment of a method which is not susceptible of great precision, and for which it is expedient to preserve its simplicity. In order that the tests may be comparative, the same sand must always be used; that of Fontainebleau seems the appointed one for tests in France. The quantity of sand which can be mixed varies from 0 to 3 times the weight of clay, according to its plasticity, and each pellet is made by adding $\frac{1}{10}$ more of its weight in sand than the preceding. If therefore a clay has been able to absorb thus $1\frac{1}{2}$ its weight of sand, its plasticity will be represented by 1·5. These being given, the following are the results obtained with some French clays:—

| | |
|---|---|
| Kaolin from Les Colettes (Allier) | 2·3 |
| ,, from Beauvoir (Allier) | 1·8 |
| Pure plastic clay from Cessey (Seine-et-Marne) | 2·4 |
| Clay from Montpotier (Aude) | 2·1 |
| Refractory clay from Forges-les-Eaux (Seine-Inférieure) | 2·8 |
| ,, ,, Provins (Seine-et-Marne) | 2·8 |
| ,, ,, Bollène (Vaucluse) | 2·5 |
| ,, ,, Vandœuvre (Aube) | 1·8 |
| Vitrifiable clay from La Chapelle-aux-Pots (Oise) | 2·3 |
| ,, ,, Jeanménil (Vosges) | 1·1 |
| Fusible plastic clay from Vaugirard (Seine) | 2·9 |
| ,, ,, Montmorency (Seine-et-Oise) | 2·5 |
| ,, ,, Chalon-sur-Saône (Saône-et-Loire) | 2·1 |
| ,, ,, Saint-Henri (Bouches-du-Rhône) | 1·9 |
| Fusible silicious clay from La Châtre (Cher) | 1·2 |
| ,, ,, Chalon-sur-Saône (Saône-et-Loire) | 1·1 |
| ,, ,, Charenton (Cher) | 1·0 |
| ,, ,, Fresnes (Seine-et-Marne) | 0·5 |
| ,, ,, Villiers-le-Bel (Seine-et-Oise) | 0·4 |

On the other hand, M. Bischof gives the following figures resulting from experiments made with a quartzy sand:—

| | |
|---|---|
| Refractory clay from Andennes (Belgium) | 1·5 |
| ,, ,, Mühlheim (Germany) | 1·4 |
| ,, ,, Oberkaufungen (Germany) | 1·3 |
| ,, ,, Grünstadt (Germany) | 1·2 |
| Kaolin from Zettlitz (Bohemia) | 0·7 |
| Refractory clay from Saarau (Germany) | 0·4 |

These results do not appear comparable with the preceding, the sand used not being the same.

It has been proposed to estimate the plasticity by forming with clay in the form of a body some briquettes having the form of those used for testing cements, by leaving them to dry, and by afterwards determining the amount of effort it is necessary to exert to effect a breakage. As the clay shrinks it is necessary to measure the reduced section and to divide the weight which has effected the breaking by the surface thus found in order to have the effective resistance per square inch. It must, however, be admitted that although the figures thus obtained are interesting to know, they could not to any degree be considered as indicating the measure of plasticity. More details on this subject will be found in the following chapter.

**54. Trials of the Fusibility.**—Tests on the fusibility should be made especially with the view of determining the manner in which the clay behaves under the influence of an increasing temperature; its porosity; its shrinkage at different degrees of heat; the temperature at which it begins to vitrify; that of the beginning of its softening. As to the temperature of the fusion properly so called, it has no practical interest. These tests are the same as more important ones to which bodies and glazes are submitted. To avoid a repetition, therefore, this question will be dealt with in Chapter VII. on firing.

It is expedient, however, to add that in reference to clays it has been sought to replace direct tests for fusibility by calculations deduced from chemical composition. By taking account of the equivalents, the ratio of the fluxes to alumina, of alumina to silica, are determined, the quotient of these two ratios being inversely proportional to the fusibility. This method, proposed by M. Bischof, only applies to clays which are clearly refractory. It will be mentioned more at length when dealing with the manufacture of refractory wares (Chapter X.).

### (b) *Trials of other Raw Materials.*

**55.** Other raw materials of bodies are sometimes tested for the purpose of affirming their composition and their purity. The following are a few summarised notes on such tests:—

Raw materials analogous to clay are tested by the processes which have just been indicated.

For silicious substances, particularly for sands, "levigation" is often resorted to. But the latter is much more simple than that of clays, and generally it is only necessary to determine the proportion of earthy materials which they can contain. For this purpose it is sufficient to agitate a given weight of sand in a test glass full of water, to pour off gently the thick liquid, and to begin this operation again until the water remains clear. The sand remaining is dried, then weighed, the difference of weight indicating the proportion of earthy materials. As the size of the grains of sand plays an important part, it is useful to determine it by means of successive sieves. At this trial an examination of the grains by a strong glass should also be made, which will enable one to recognise fairly easily the mineralogical nature of the sand.

When it is desired to carry on the operation with accuracy this test is not sufficient, and chemical analysis alone is capable of revealing the traces of fluxes which the silicious materials can contain. As the fluxes can be in the form of feldspar, the material should be attacked by hydrofluoric acid, that is to say, by ammonium fluoride, according to the process indicated previously. Only, instead of treating the solution by baryta, which precipitates all the bases, it is divided into three parts. In the first the alumina and oxide of iron are separated by ammonia, lime by oxalic acid, and magnesia by phosphate of soda. With the second the oxide of iron is treated with permanganate of potash; and, lastly, the third is employed for the determination of alkalies, according to the known process. Sands are also sometimes the object of tests of fusibility.

Alkaline fluxes should be analysed by attacking them also by hydrofluoric acid. For calcareous fluxes it is sufficient to dissolve them in hydrochloric acid and to determine the alumina, oxide of iron, lime, magnesia, according to the general method. The insoluble

portion is considered as a mixture of quartz and clay, which can be separated by levigation, or analysed by attacking them with carbonate of soda or ammonium fluoride.

The analysis of sulphate of lime should be preceded by a calcination at 200° C. in order to remove all water of the hydrates; then an attack is made for twenty-four hours, without heat, by carbonate of ammonia. Sulphate of lime is decomposed into carbonate of lime and into sulphate of ammonia. This last is separated by filtering, then the warm liquid is treated by chloride of barium, which precipitates sulphuric acid in the form of sulphate of baryta, the form under which it is treated. The filtered residuum is taken up again by hydrochloric acid, and the analysis is made in the same way as for lime.

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# CHAPTER III.

## PLASTIC BODIES.

SUMMARY I.—*Properties and Composition:* Chemical Composition — Forms and Proportions of Water in Bodies—Texture—Consistency—Plasticity.

SUMMARY II.—*Preparation of Raw Materials:* (*a*) *Disaggregation:* Processes of Disaggregation—Natural Disaggregation—Disaggregation by Heat—Stampers—Centrifugal Grinders—Ball Grinders—Chopping Machines—Vertical Mills—Rolling Grinders — Cutters — Granulators. (*b*) *Purification:* Processes of Purifying — Sorting — Sifting — Washing of Clays — Clay Blungers — Sand Separators — Settling Tanks — Levigation of Sands — Ventilation — Electric Purifying—Chemical Purifying.

SUMMARY III.—*Preparation of Bodies:* Processes of Preparation of Bodies. (*a*) *Preparation by Plastic Method:* Apportionment of Raw Materials and of Water—Homogeneisation of Bodies—Grinding or Rolling—Pugging—Rolling and Pugging Combined—Preparation of Stiff Body. (*b*) *Preparation by Dry Method.* (*c*) *Preparation by Liquid Method:* Methods of Preparation by Liquid Process—Blunging of Raw Materials—Apportionment and Mixing in Liquid State—Sifting—Stiffening—Pugging and Wedging or Slapping.

### I. PROPERTIES AND COMPOSITION.

**56. Chemical Composition.**—Besides hydrosilicates of alumina and water, which are their essential elements, plastic bodies contain four acids: silica, carbonic acid, rarely sulphuric and phosphoric acids, and six bases: alumina, oxide of iron in different degrees of oxidation, lime, magnesia, potash and sodium. Other substances, which are occasionally found in small quantity, are only accidental impurities of raw materials. By not taking water into account, the following figures indicate the proportions in which these different substances can enter into the "global" composition of the bodies.

*Silica.*—Silica is the principal element of nearly all bodies. They generally contain from 55 to 80 per cent. of it. This proportion is exceeded in refractory silicious wares, in which it can amount to 98 per cent. It does not reach this in certain refractory aluminous wares, in which it can be reduced to 20 per cent.

*Alumina.*—The proportion of alumina varies from 10 to 40 per cent. It falls to less than 1 per cent. in silicious refractory bricks, but sometimes reaches more than 70 per cent. in aluminous refractory wares.

*Oxide of Iron.*—Iron is generally present in the form of a peroxide. At this degree of oxidation its proportion varies from 0 to 8 per cent., this figure being surpassed in certain stonewares, when it reaches even 20 per cent.

*Lime.*—The amount of lime contents is generally between 0 and 10 per cent., but for some terra cottas and faiences it can amount to 20 per cent.

*Magnesia.*—Magnesia, which generally accompanies lime, only enters into the composition of bodies in a small proportion, except in rare cases when it does not exceed 2 per cent.

*Potash and Sodium.*—These two bases are generally placed in analysis under the common name of alkalies. Their proportion varies from 0 to 5 per cent. Exceptionally, as in the case of vitreous porcelain, it can reach 17 per cent.

*Carbonic Acid.*—This acid is found in bodies in combination with other bases, principally with lime. Its proportion can amount to 17 per cent. When the temperature is sufficiently high it disappears completely during the firing.

*Phosphoric Acid.*—This acid is only introduced into bodies in the form of phosphate of lime for the manufacture of soft English porcelain. They can then contain as much as 35 per cent. of it.

*Sulphuric Acid.*—This acid is generally combined with lime. Many clays contain small proportions of it, but it is rarely introduced voluntarily into the body.

The chemical properties of substances which enter into the composition of bodies exert no influence on their preparation, their formation and their drying, but, on the other hand, play an important part during firing (Chap. VII., 5). When studying the composition which must be given to a piece of pottery in order that it may fulfil the conditions imposed on it, two points present themselves:—

(1) The manufacture in question is carried on for the purpose of utilising a given clay, which is most frequently the case

for fired bodies. Its physical properties are first studied, research is made to discover what mixtures must be added in order that the body may easily lend itself to shaping and to drying. This being done trials are made in firing, and from the results obtained it is seen if there is any ground or not to modify the composition first adopted. In this case chemical analysis of the clay only indicates, a priori, if it can be used for the manufacture proposed.

(2) The manufacture in question has as its aim the production of a certain class of ware, and it is necessary to find out by what mixtures this result can be obtained.

This is generally the case with faience ware, stoneware and porcelain.

This is based then on a given chemical composition, from analogy with similar productions, and, by comparing the composition of substances which can be prepared, the materials which must be used and the proportions of the mixture are determined. Then trials are made to ascertain if the physical properties are suitable, and experiments in firing are made. From the results obtained the raw materials are modified, or the proportions of the mixture, or, if necessary, even the chemical composition first adopted.

These trials are generally rather long on account of the many qualities the pottery ware must possess; the history of ceramic discoveries can prove this, but the use of chemical analysis, unknown to the ancients, enable them to be considerably shortened.

The fairly long calculations, which the investigation of the proportions of a mixture of raw materials necessitates for the obtaining of a given composition, can also often be simplified by making use of the following graphic method, proposed by M. Bourgerel :—

At the extremities of an horizontal line 20 centimetres long, two perpendiculars of 10 centimetres are drawn, which are marked off in divisions corresponding to the centesimal composition of the two materials which are proposed to be mixed together.

Thus, for example (Fig. 3), in mixing a kaolin containing 66 per cent. of silica, 30 per cent. of alumina, 4 per cent. of

oxide of iron, and a feldspar of the following composition: 76 per cent. silica, 10 per cent. alumina, 14 per cent. alkalies, the perpendicular on the right is divided into three parts of 66, 30 and 4 millimetres, and that on the left also into three parts of 76, 10 and 14 millimetres, then lines are drawn joining each of the points so obtained.

If a graduated rule is passed from left to right of A B, the proportions can be measured of the different mixtures which can be obtained with the two substances in question, or if the contents of one of the elements are prescribed the proportion of the others can be read and that of the corresponding apportionment of the raw materials.

**57. Forms and Proportions of Water in Bodies.**—The water contained in bodies is in the state of water in combination, hygrometric water, and water of formation.

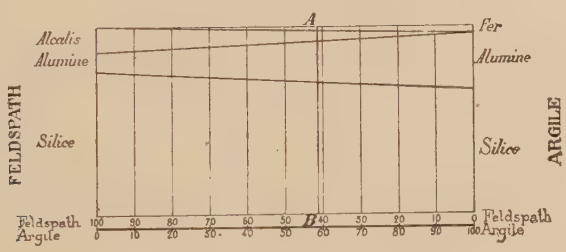


FIG. 3.—Diagram of Body Mixtures.

The water in combination is that which a body dried at 120° C. contains, and which only disappears during firing at a higher temperature than 400° C. It has been seen that this water is supplied by hydrosilicate of alumina, which contains 13·90 per cent. of it. It is only quite exceptionally that the water of hydrate of alumina, of halloysite, of lenzenite, of cimolite, of bauxite, of talc, of magnesite, etc., is added to it. As a general rule then, it can be admitted that the water in combination is proportioned to the alumina contents. A very simple calculation shows that for 100 parts of alumina there should be 34·95 per cent., or, in round figures, 35 per cent. of water. As has been seen from the preceding, the alumina contents in anhydrous bodies varies from 10 to 40 per cent., consequently a body dried at 120° C. ought still to contain from 3·4 to 11·9 per cent. of water in combination.

Hygrometric water is that which a dried body loses in contact with the air and with the surrounding temperature when it is heated to 120° C. Usually the greatest part of this water proceeds from the absorption of the atmospheric humidity by pure clay.

The quantity of water so absorbed depends on the temperature and the hygrometric state of the air, it is therefore necessarily variable. For very plastic bodies it can reach 10 per cent. and fall to 2 per cent. for non-plastic bodies, the medium varying between 4 and 6 per cent.; the ordinary opening substances, quartz, sand, carbonate of lime, are not hygroscopic. On the other hand, other substances can increase the proportion of hygrometric water; these are hydrates of silica, oxides of iron, allophane, collyrite, and especially organic substances. These last when they are in a considerable proportion can even raise the contents of hygrometric water to 20 per cent.

Water of formation is the water added to the body to give it the plasticity and consistency necessary to the mode of shaping adopted. It evaporates completely when the body is left for a sufficient length of time in a dry atmosphere.

As has been seen, the action of the water of formation consists solely in getting between the grains of the body, giving to them a certain mobility, enabling some to be displaced by others. It should not only fill the spaces which are found between them, but should also cover their surface with a thin, liquid layer. Its action is therefore purely mechanical, and its volume for bodies having the same amount of consistency only depends on the form and the size of the grains, and not on their chemical composition. It unites with the hygrometric water properly so called, and it is necessary in all questions relating to the plasticity to take note of this total quantity of water.

**58. Texture.**—If plastic bodies were composed only of pure clay their texture would be represented by imagining grains of extreme fineness of lamellar form, very close together and entangled one with the other, the spaces which separate them being filled by much smaller molecules still of water.

The addition of other materials to pure clay has the effect

of modifying this view. All substances liable to enter into the composition of bodies have in fact much coarser grains than pure clay, a volume of 10, 100 or 1,000 greater. An idea of the texture of a plastic body can be formed by considering grains of varying coarseness, around and between which are much smaller grains of pure clay, the spaces being filled by molecules of water, infinitely small.

If for the same quantity of clay the proportion of grains of other materials is constantly increased, there comes a time when the clay grains are not sufficiently numerous to surround the others, or even to fill the spaces which are left between them. From this moment the clay is no longer capable of cementing the other grains; if there still remains a certain amount of plasticity the cohesion of the body is destroyed, and the latter crumbles into dust as soon as the water is evaporated. It is this limit of proportion of foreign substances which a clay is capable of agglomerating which one endeavours to find out by adding to a clay increasing proportions of sand up to the time that the dry body begins to crumble at the least rubbing.

Moreover, it is clear that the smaller the grains are of antiplastic materials, the less spaces will there be between them, and the more of them will the same quantity of clay be able to agglomerate. Hydrates of silica, alumina, peroxide of iron, and mica in impalpable powder seem to yield the finest grains, then come carbonates of lime and of magnesia, and finally feldspar and quartz.

This illustration of the texture of bodies shows that the more antiplastic grains there are in a body, and the coarser these grains are, the less amount of water is necessary to give it an equal consistency. From this point of view the quantity of water contained in a body can serve as an indication of the coarseness of the grains of which it is composed.

In the formation of three trial pieces, one with plastic clay containing 6 per cent. of hygrometric water, the other formed half of clay and half of carbonate of lime (chalk in impalpable powder), and the third of clay and sand (fine sand of Fontainebleau) in the same proportions, it has been found that the

following quantities of water must be added to 100 parts of dry materials in order to obtain bodies of equal consistency:—

| | |
|---|---|
| Pure clay . . . . . | 35·5 per cent. |
| Half clay, half carbonate . . . . | 27·7 ,, |
| Half clay, half sand . . . . . | 19·5 ,, |

Remembering that there has been besides 6 per cent. of hygrometric water in the first body and 3 per cent. in the other, we see that—

100 parts of clay require 41·5 parts of water.
100 parts of carbonate require 19·9 parts of water.
100 parts of sand require 3·5 parts of water.

If, on the other hand, we consider a body in the form of dry powder, that is to say, containing only its hygrometric water, its volume can be diminished by beating it down, then by submitting it to the action of a strong pressure. By these operations the smallest grains are forced to place themselves in the spaces left between the larger, but it is impossible, whatever pressure is exerted, to entirely fill the spaces.

It is agreed that hydrosilicate of alumina has a density of about 2·4. As bodies contain a more or less large proportion of silica, the density of which varies from 2·6 to 2·7, that of the bodies varies between 2·4 and 2·5 when they contain neither hygrometric water nor water of formation.

By strongly compressing a dry body at the utmost an apparent density can be given to it, that is to say, that it will always contain at least about 20 per cent. of spaces.

The addition of water to bodies evidently diminishes their density: the density of bodies containing from 25 to 30 per cent. of water in weight is from 1·6 to 1·7. If, after formation, this water is allowed to evaporate, the dry bodies resulting have a density apparently varying from 1·82 to 1·73.

Thus a plastic body containing only 5 per cent. of hygrometric water, compressed at a pressure of 23·66 hundredweight per square inch[1] in the form of tiles of ·47 inch in thickness, had an apparent density of 1·98. This same clay when prepared in the form of a body and dried had densities of 1·74 and 1·79,

[1] These tiles have been manufactured by MM. de Smet & Cie, Lille. The pressure noted has not been able to be surpassed, because beyond that the clay sticks to the moulds.

according as the body had been slightly or strongly ground. Then being placed in suspension in water and left to settle slowly, and afterwards dried, it gave a dry body of 1·82 apparent density. In the first case there was 19·2 per cent. of space, 29 and 27 per cent. in the second, and 25·7 per cent. in the third.

We must also note that dry bodies always contain air, and by the addition of water this air is not often completely eliminated. In plastic bodies it can remain in the form of bubbles. When this is the case it can be observed that the body, after having been compressed slightly, increases in volume in consequence of the electricity of the air.

**59. Consistency.**—The consistency which it is suitable to give to a body depends on the mode of formation to which it is desired to subject it. From this point of view the following distinctions are made in ceramics:—

(1) Dry bodies, which can only be agglomerated under a powerful pressure, and which even in this state always preserve a granulous appearance.

(2) Stiff bodies, which also need for agglomeration a mechanical pressure, although not so great; the wares resulting are smooth, and offer the same resistance as leather to the pressure of the finger.

(3) Half-stiff bodies, which can be shaped, though with difficulty, by hand, but uniting badly under the simple pressure of the fingers.

(4) Half-soft bodies, which can be shaped and welded easily by hand, and preserve the form which has been given them.

(5) Soft bodies, which do not lend themselves well to shaping, but stick to the fingers. The objects formed have a tendency to lose their shape under their own weight.

(6) Liquid bodies, fluids, which have to be placed in receptacles.

According to this classification, it is seen that the consistency is estimated by the touch. Up to the present this method, certainly very rudimentary, has been sufficient for all purposes, and it seems probable that it will be so in future. If, however, for more exact experiments, the usefulness of an exact measure is felt, a needle having a given section could be employed; for example, a needle ·039 inch square, weighing from 1·60 to 3·20

ounces, could be allowed to fall from a height of 3·93 to 7·86 inches on the body of which it is desired to determine the consistency. The depth to which it penetrates, measured in millimetres, would serve as a measure.

The quantity of water which a body must contain to take the different degrees of consistency depends, as has just been said, on the texture: open bodies require much less than plastic. It is difficult, taking into account the considerable digressions which can be produced, to indicate even approximate figures. Thus the following proportions ought only to be taken in virtue of indications, the smallest number corresponding to very open bodies, and the highest to very plastic bodies.

| Consistency. | Hygrometric Water and Water of Formation. Per Cent. |
|---|---|
| Dry Body | 7 to 18 |
| Stiff body | 10 to 20 |
| Half-stiff body | 12 to 25 |
| Half-soft body | 15 to 30 |
| Soft body | 17 to 35 |
| Liquid body above | 20 to 40 |

**60. Plasticity.**—The causes of the plasticity of pure clay, the influences which other materials mixed with bodies can have on this property, as well as its measure, have been studied in the preceding chapter. It now remains to examine in what limits it can vary according to the degree of consistency of the body and the pressure to which it is subjected during formation.

If to a moderately plastic dry body is added more and more water, the observation is as follows: The body, first devoid of plasticity to the touch, gradually assumes it; it can at first be moulded with difficulty, then more easily, and finally be formed with the greatest facility. But if from this moment one continues to increase the proportion of water, the body begins to adhere to the fingers, then it soon becomes impossible to form it.

There exists then for this body a given proportion of water, for which the shaping by hand is easiest. With less water too considerable an effort must be exercised, with more water it lacks cohesion and sticks to the fingers. For a moderately plastic body the consistency which corresponds to this proportion

of water is that which has been noted under the name of "half-soft body" in the preceding article.

If the same experiment is begun with a more plastic body, it will be observed that the most favourable proportion of water for moulding by hand corresponds to a stronger consistency, that of a half-stiff body; if it is desired to give it the consistency of a half-soft body, it will adhere to the fingers and will allow of no further shaping. Now, as the body at this half-soft consistency does not lend itself well to shaping by hand, it is seen that it is only possible to shape this body by hand by opening it, that is to say, by diminishing its plasticity.

The same observations could be made, but in an inverse sense, for an open body. The latter only acquires the desired plasticity by having a very soft consistency, which does not allow it to support itself and to preserve the given form. It must be rendered more plastic if it is desired that it should lend itself well to shaping by hand.

The plasticity of bodies which are to be formed by hand must be comprised between two limits—maximum and minimum—in such a manner that when they are given the consistency of a half-soft body they can be shaped without adhering to the fingers, and without being too open. In returning to the method described in the preceding chapter for measuring the plasticity, we can say that bodies must be able to absorb from once to twice their weight of sand to remain between these limits.

If now, instead of dealing with the formation by hand, we consider it done by means of mechanical machines, in which the body is subjected to a much stronger pressure, we shall see that in order to obtain the same plasticity, less water must be added to the body, that is to say, it will be expedient to form it with a stronger consistency. Pressure then plays the same part as water in relation to the plastic qualities of bodies, the one can partially be replaced by the other, or, in other words, when one increases the other should diminish.

In returning to the trials of the texture of bodies, we see that a plastic clay has been shaped with the minimum of water which it can have, that is to say, only containing 5·0 per cent. of hygrometric water. The pressure has been 1,161 lb. to the

square inch; it would have been impossible to increase it because the clay would have adhered to the mould. On the other hand, trials have shown that the same clay, placed in the form of a body containing 22·9 per cent. water, began to adhere to an iron mould for a pressure of 28·83 lb. per square inch, and that for a body having 26·4 per cent. of water a pressure of 5·64 ounces was sufficient to determine adherence.

If it had been desired also to shape a more open clay in dry body, the pressure would have had to have been increased in the same way as, in order to shape it by hand, one is led to give it a softer consistency.

The relations which must exist between the plasticity on the one hand, the consistency and the pressure corresponding to the mode of formation adopted on the other, can be summarised in the two following propositions:—

(1) Given a body of fixed plasticity, there exists a maximum of pressure and a minimum of consistency between which the body can be formed.

If the body is too plastic, this maximum pressure will be less great, and, on the other hand, the minimum of consistency will be too great to permit of formation by hand, or by a slight pressure. If the body is too open the maximum pressure will become considerable and the minimum consistency will yield a body which is too liquid to be able to be formed.

(2) Given a mode of formation corresponding to a pressure and consistency which are fixed, the plasticity of the body employed can only vary between certain limits.

If it is too plastic if will adhere to the machines used for formation. If it is too open its grains will not unite among themselves, and it will be impossible to make a compact mass of them.

It is then of the highest importance to choose well the mode of formation for a body of given plasticity, or to duly give to a body the plasticity suitable for the mode of formation. We shall see presently that the solution of these problems is often rendered more difficult by the special qualities which the bodies must have in order to give good results in drying and firing.

The properties of plastic bodies having been thus defined, we shall study the processes employed to manufacture them.

## 2. Preparation of Raw Materials.

### (*a*) *Disaggregation.*

**61. Processes of Disaggregation.**—The aim of disaggregation is to place the raw materials which are found in the form of rocks or of agglomerates in such a condition that they can be afterwards more easily mixed and transformed into a body. It does not concern itself with pulverising them, an operation which can be made subsequently in the manufacture of the body properly so called, but only with grinding or dividing them. From this point of view raw materials can be classified in three categories :—

(*a*) Clays, sometimes dry, sometimes humid, friable in themselves, but sometimes containing fragments of more or less hard rocks.

(*b*) Rocky materials, or soft agglomerated.

(*c*) Hard rock materials.

The processes of disaggregation, naturally variable according to the nature of the materials to be treated, are three in number :—

(1) Natural disaggregation, applicable only to clays.

(2) Disaggregation by heat, sometimes employed for clays and hard rocks.

(3) Mechanical disaggregation by means of very diverse machines, but which can be classified as follows, according to their mode of action :—

| | | |
|---|---|---|
| Concussion . . . | Stampers . . . | Used for hard materials. |
| | Centrifugal Grinders . | Used for dry clays, soft and hard materials. |
| Concussion and Crushing . | Ball Grinders . . | Used for dry clays, soft and hard materials. |
| Crushing . . . | Chopping Grinders . | Used for hard materials, dry clays. |
| | Vertical Mills . . | Soft and hard materials. |
| | Flattening Machines . | Used for humid material, soft and hard materials. |
| Cutting . . . . | Cutters . . . | Used for humid and dry clays. |
| | Granulators . . | Used for humid clays. |

**62. Natural Disaggregation.**—Clays always contain at the time of their extraction a certain quantity of water, called

"coursing water," which evaporates when allowed to remain in a sufficiently dry and warm atmosphere. When this evaporation takes place fairly rapidly it causes cracking and the disaggregation of the balls of clay. It is, in fact, easy to account for. The evaporation at first only taking place on the surface of the balls of clay causes contraction there, a shrinkage of the clay in which the centre of the ball, still humid, cannot participate. The consequence is that the tensions cause the surface to crack, then gradually all the ball, which ends by disaggregating, and falls into small fragments. It is understood also that this action is as much more energetic as the evaporation is more rapid, and cannot be produced if the drying takes place very slowly.

This natural disaggregation, which is a consequence of the plasticity of clays, is employed in a very efficacious manner for the preparation of plastic clays, always very compact. On the other hand, it presents few advantages for open clays naturally friable.

In countries where the nature of the climate allows it, clays are for this purpose laid out in the air, exposed to the sun in pieces of the size of the fist. In the summer a few hours are generally sufficient to cause complete disaggregation of the balls. The clay is then collected and placed in warehouses ready to be used for the preparation of bodies, whether by dry, pasty or liquid method. When, on the contrary, the climate is frequently rainy, the clay is placed in the outlet of a course (quarry) in a slightly thick heap under well-aired sheds, where it usually, at the end of a period more or less prolonged, becomes disaggregated, although less completely than in the preceding case.

When the preparation of the body must be made by a pasty method, or by liquid, if the clay is fairly dry in the course, it can, on the contrary, be soaked or exposed to the action of the rain. In this case the inverse phenomenon is produced: the surface of the balls imbibing the water expands, while the centre, being still dry, does not increase in volume. The result is also disaggregation. For this end it is convenient to give to the heaps of clay only a slight thickness, 3 feet 3 inches at the greatest, so that the rain can penetrate them. If artificial water is added

the heaps can be made thicker on condition that holes are bored at distances from each other, through which the water can penetrate to the centre.

Then in countries where the climate is severe enough for it to freeze regularly every winter, clay is extracted during that season and exposed in heaps from 2 feet 6 inches to 3 feet 3 inches thick to the action of the cold. The water of formation is then transformed into ice, and the resulting increase of volume disaggregates the balls, which become completely displaced at the moment of thawing. This action is rendered more powerful when care has been taken to sprinkle the clay before the frost arrives, so as to saturate it with water.

It will be seen then that, whatever the climate, clays can be disaggregated, which serve for the preparation of the body, by making use of solar heat, rain or frost. But it is necessary, before adopting a process of natural disaggregation, to know well the average climate of the locality, and the humidity of formation of the clay.

This natural disaggregation of the clay should be practised every time that it is possible, especially in the case of plastic clays, for it has a considerable influence on the good preparation of bodies, and on the final quality of manufactured ware. Mechanical means of disaggregation can doubtless replace it partially, but only at the price of laborious and much more costly work. Moreover, experience proves that with the same stock of tools, and the same expenditure of force, 6 cubic feet of body can be prepared with a disaggregated clay, while only 3 or 4 can be obtained with the same clay from formation.

In the old traditions of the potter's art the preservation of the clay in a warehouse for very long periods played a considerable part. Often it was only used at the end of several years. Without falling into exaggeration it must, nevertheless, be recognised that the use for the preparation of bodies of mechanical machines has often caused the advantages of natural disaggregation to be forgotten: in the hope of accomplishing a prompter manufacture grave disappointments have frequently been experienced.

**63. Disaggregation by Heat.**—Disaggregation of clays can

also be obtained by artificial drying. This method is employed in humid climates, or when waste heats are disposed of.

The artificial drying of clays is not so simple an operation as would be thought at first sight, because the temperature ought not sensibly to exceed 100° C, and in any case must remain at less than 200° C, if the clay is to retain its plasticity. For small productions the process most employed consists in placing the clay on iron floors, sheet-iron, or on refractory slabs, heated in the interior part by a system of pipes, in which the gas circulates as it comes from a grate, making its way to a chimney. The thickness of the plaques or slabs should be regulated so that the heat transmitted may be uniform at all points on the area, and that in any case the temperature do not exceed the limit previously noted. The clay placed in the form of a layer from 6 to 9 inches should be disturbed from time to time in order to hasten the operation, and to avoid an overheating in contact with the area. By this system of drying a considerable quantity of heat escapes by the chimney, and the surface occupied by the apparatus is fairly considerable, thus it can only be employed for small productions, in which the price of net cost does not play a preponderating part. Of course this observation does not apply in the case when these escaping heats are made use of.

For large productions recourse must be had to more economical dryers and to larger output. Numerous systems have been proposed, but now it is agreed to give the preference to dryers in the form of sliding furnaces, into which the clay is introduced in the upper part, and makes its exit below in a dry state, the process being carried on in a continuous manner.

Fig. 4 represents a stove of this kind, invented by M. Lecaze, and is a modification of his stove for plaster. The clay is placed in balls in an upper mill hopper, which should always be more or less filled. From there it penetrates into the dryer, properly so called, when it circulates round two rows of furnaces, heated by coke or thin coal, so as to give a large quantity of air at not a very high temperature. When the clay is dry it is extracted from the lower part at regular intervals, this extraction causing the descent of the whole of the upper mass. The air

being charged with vapour makes its exit by a series of openings pierced in the arch supporting the mill in order to enter into two longitudinal pipes, and from there into small chimneys prepared in the thickness of the extreme walls.

This stove is about 23 feet high, 6·50 feet wide, and respectively 13 feet, 23 feet, 30 feet long for wares of 530, 1,060, 1,760 cubic feet in twenty-four hours. A clay containing 13 per cent. of water requires 1·9 to 2·2 lb. of coke per cubic foot in order to dry it in such a manner that it contains no more than 3 to 5 per cent. of water.

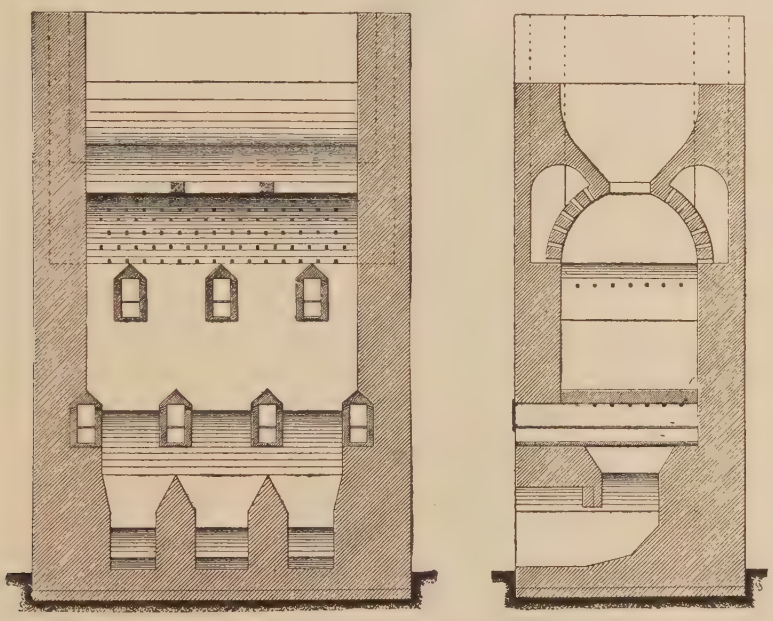

Fig. 4.—Kiln for Drying Clay.

Fig. 5 represents a stove constructed by MM. Smidth & Cie. It consists essentially of a chimney, in which, towards the centre of its height, the clay is introduced by an inclined mill. The balls of clay descend between the exterior wall of the chimney and a central block of stone work, to be extracted dry by many lower openings. The heat is supplied by an exterior of stone, a ventilator bringing in the air for this stove, and by a series of apertures pierced in the vault of the pipe connecting the stove with the interior void of the central block. The warm air escapes from this space by

numerous orifices, and, after being saturated with water in contact with the clay, makes its exit by the chimney. This stove is used chiefly for large outputs and for very humid plastic clays.

Heat is also employed to disaggregate quartz or silex. It

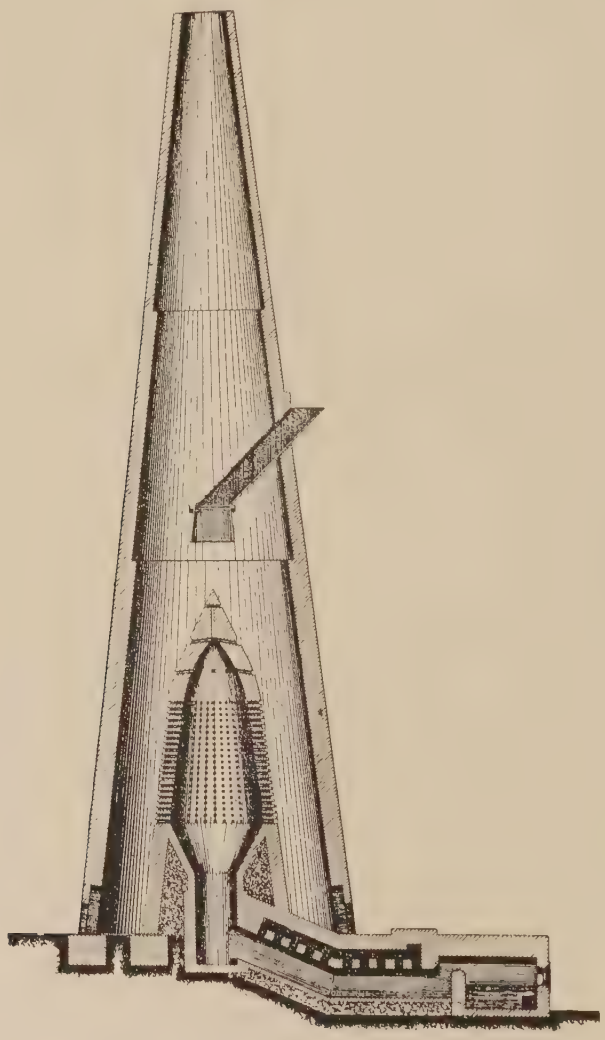

Fig. 5.—Kiln for Drying Clay.

is also sometimes made use of for feldspar. These hard rocks are heated at a fairly high temperature, and then cooled more or less briskly. The expansion and contraction which result therefrom are powerful enough to excite in the interior of the

mass sufficient tension to break it, and even to disaggregate it completely.

Heating was formerly carried on in reverberating kilns. The rocky substances were placed on the floor, and were subjected to the action of the flame evolving from the fire. This method of heating is not very economical, and is only used for very small productions.

Now sliding kilns are used, similar to those employed for burning lime. As in the latter the action can be intermittent or continuous, and the heating is done either by means of fire

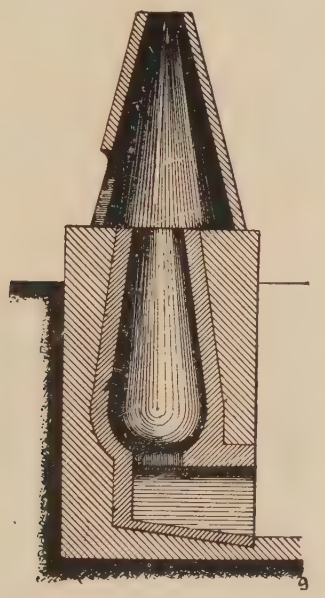

Fig. 6.—Kiln for Calcining Flint.

holes placed round the kiln, or by mixing the fuel with the stone. The intermittent action is naturally the more laborious, and it is only justified for small wares. Besides, kilns with independent fires are not very economical, and there is only occasion to use them when one is obliged to make use of fuel producing a great deal of slag, which sticks to the rocky substances and can only with difficulty at length be separated from them.

Fig. 6 represents, in section, the kind of furnace which is most generally used for the disintegration of flint. It is composed of a truncated vat, surmounted by a chimney, and ter-

minated by a grating, with an opening for the drawing out at the lower part. Wood is first placed on the grating, and is covered with alternate layers of stone and fuel in equal proportions, so as to completely fill the stove. After having set light to it, stone and fuel are successively introduced by the furnace mouth in proportion as the mass descends, in consequence of the spaces caused by the combustion. As soon as bluish flames are observed to appear on the upper surface, the bars are removed from the grating, the mass falls and forms a sloping heap in the passage of the oven mouth; the space formed at the upper part is filled up and the kiln is definitely in work. When the blue flames appear at the furnace mouth it is sufficient to draw, by means of hooks, a certain quantity of rocky substances from the lower part and to fill up the space produced at the upper part by a new loading.

In the continuous progress the proportion of fuel is reduced to about a third part of the volume to be heated. The fuel which gives the best results is wood-charcoal, but because of its high price it is generally replaced by coke as pure as possible.

The burnt flints extracted at the lower part are either well precipitated in water or left to cool in the air. In the first case the disaggregation is more complete, but the second process must be resorted to when rather impure fuel is used, when it is necessary to remove by hand the slag which adheres to the rocks.

The preceding furnace is as much as possible caused to lean against a piece of rising ground in order to allow of an easier feeding of the materials to be disaggregated and of the fuel. Of course it can be built detached on horizontal ground, but in this case it is better to make it circular externally, and to strengthen it with solid iron braces. The height of the chamber is from 9 to 12 feet, the diameter of the furnace mouth from 35 to 40 inches, and that of the widest part from 55 to 63 inches.

Disaggregation by heat is nearly always only a preparatory operation, which is completed by mechanical concussion, rendered much easier by the friability of the stone.

**64. Stampers.**—Stampers, which imitate the manual work of

a workman with a hammer, were for a long time the only mechanical machines for crushing employed in ceramics. They have the objection of yielding grains of unequal size, of wearing out rapidly, of making a feeble production, and occasioning a deafening noise. They are no longer employed except for crushing hard materials into small fragments.

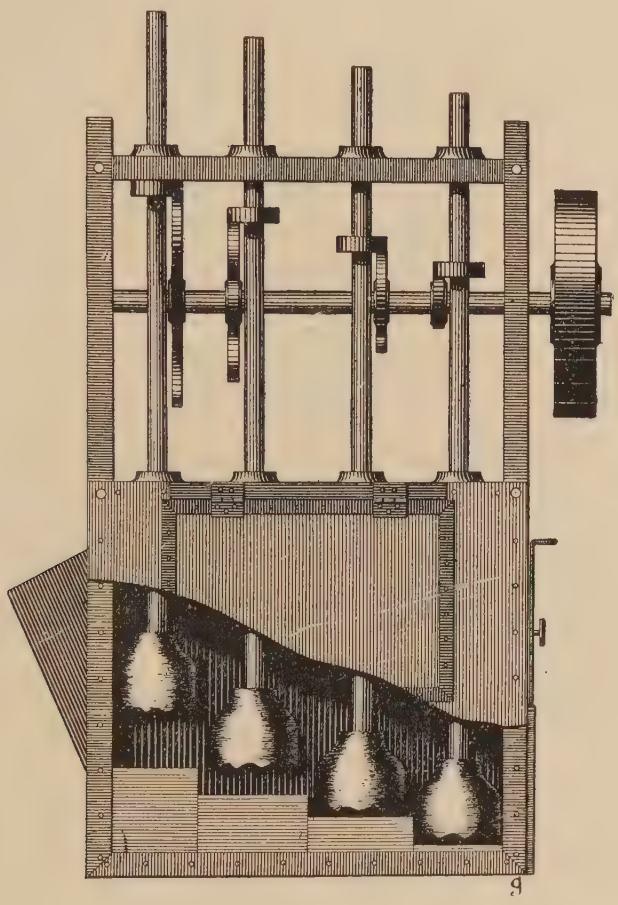

Fig. 7.—Stampers.

The apparatus is generally composed of several stampers, raised successively above each other by cogs, mounted on the same horizontal beam. These stampers are placed in a coffer and fitted with shelves in such a way that the material to be crushed, being introduced at one extremity, falls successively under each blunger before going out at the other extremity. The stampers and the anvils are of iron or brass, when the in-

troduction of a certain quantity of iron into the material offers no objection. In the contrary case, the lower parts of the stampers and the anvils are covered with hard stone. Sometimes the anvils are pierced with holes, having the dimension of the grains which it is desired to obtain, and by which the pounded material makes its exit.

For small productions a single stamper is made use of, which is moved by hand by means of a flying handle.

65. **Centrifugal Grinders.**—Centrifugal grinders are rotating machines, turning with great speed, in which the material to be ground is introduced near the centre and projected by the centrifugal force towards the circumference, receiving on its course numerous shocks. They can be employed in the grinding of all raw materials used in ceramics; they can also be used for pulverisation, on condition that the powder is afterwards sifted, either on its exit from the grinder or in a separate sifter. However, they are not suitable for too humid clays, as in this case they have a tendency to be choked up. They must also be avoided for materials which must not contain any trace of iron. Their large output and the employment of a motive force, which is rather considerable, limit their use to factories working with a large quantity of raw materials.

There is rather a large number of different types of centrifugal grinders, which is explained by their many applications to very different kinds of ware, and at the outset one type cannot be preferred to others without the special purpose it is proposed to attain being known.

In England the Carr Disintegrator is very much used, especially in factories for refractory wares, for the pulverisation of fired bodies (grog or rough stuff). It consists (Fig. 8) of two discs, each carrying two circular ranges of steel bars, turning in a contrary direction, the whole being placed in a sheet-iron casing. Each disc is fitted at the extremity of an horizontal shaft worked directly by a pulley. The material to be ground is introduced by a mill at the centre of the apparatus. There it falls on to the first circle of bars, which strike it, projecting it in one direction in order to be struck by the second circle, turning in an opposite direction, then by the third, turning in the same

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direction as the first, and then by the fourth, conjointly with the second. The material ground collects at the bottom of the box, whence it can be removed by a screw, or quite a different arrangement, which prevents the exit of the dust. The speed of the machine is regulated according to the degree of fineness which it is desired to obtain. For a complete pulverisation six ranges of bars are often used instead of four.

The Carr Disintegrator is built on several different models, according to the ware which it is desired to obtain. Here are some figures on this subject:—

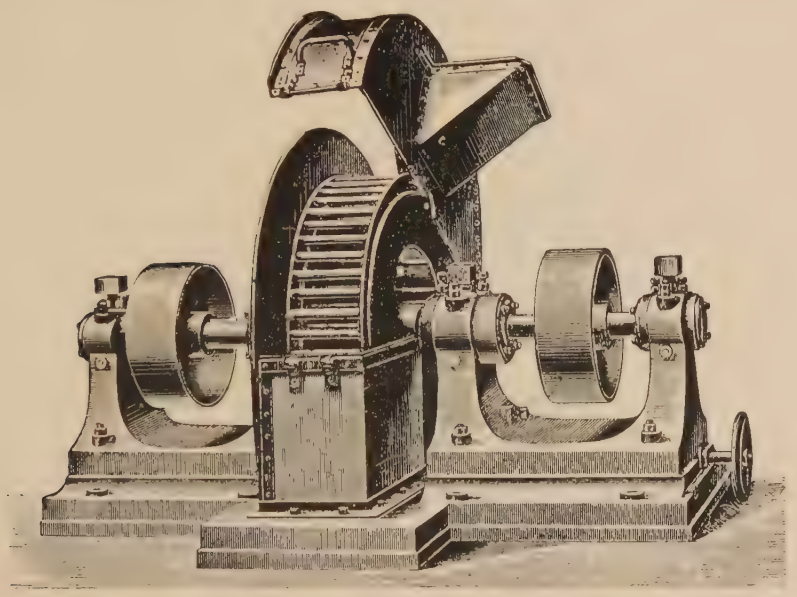

Fig. 8.—Carr's Disintegrator.

| | | | | |
|---|---|---|---|---|
| Diameter of external disc in feet . . | 6·562 | 4·921 | 3·281 | 1·64 |
| Number of revolutions a minute . . | 300 | 350 | 450 | 600 |
| Production in lb. per hour . . . | 44,680 | 26,800 | 9,000 | 340 |
| Horse-power used . . . . . | 36 | 20 | 4 | 1·5 |

The Loizeau Grinder, constructed by Messrs. Weidknecht-Schoeller, consists of a strong case, carrying on its upper part a mill employed for the introduction of the materials and supplied in the interior with steel gratings, one sloping, the other arched, pierced with holes, through which the ground material has to pass. A horizontal shaft, turning with great speed, is surrounded by a "manchon," the sides of which are traversed by small shafts,

which are employed to support movable jointed hammers weighing, according to the type of the grinder, from 4·46 to 22·34 lb. The material falling through the mill is struck by the hammers and projected against the grills, which allow the pieces which are sufficiently reduced to pass. The others are struck again by the hammers until they have the size required to allow the pieces to pass out of the apparatus. The jointing of the hammers allows ruptures to be avoided in cases of introduction into the apparatus of pieces having an abnormal resistance. The fineness of the grinding is regulated according to the openings of the grids and the speed of rotation. The grids capable of supporting the greatest amount of wear and tear are of careful manufacture and replacements can easily be made.

MM. Weidknecht-Schoeller construct several patterns of this grinder, of which here are some:—

| Production per hour. | Power used, | |
|---|---|---|
| 1 to 1·5 tons. | 2 to 3 horse-power. | |
| 1·8 to 2 ,, | 5 to 7 ,, ,, | |
| 2 to 2·5 ,, | 2 to 3 ,, ,, | (Large grains.) |
| 8 to 10 ,, | 8 to 10 ,, ,, ,, ,, | |

The largest grinder constructed by M. Bordier is formed by three horizontal stands fixed on a vertical beam, and carrying arms placed according to the beams. The whole is enclosed in a cylindrical casing, having two funnels between the stands, and the toothed segments in front of them. The materials are brought to the centre of the upper tray, and projected by the action of the centrifugal force against the first row of toothed segments. From there they fall into the first funnel, which leads them to the centre of the middle tray in order to be thrust against the second row of segments. The same operation takes place on the third tray, below which are fixed float boards, which cause the ground materials to make their exit by a lower. This grinder is especially used in France and Belgium in factories for refractory wares. The four types in use in ceramics are the following:—

| | | | | |
|---|---|---|---|---|
| External diameter . . . . . | 1·75 | 1·30 | 1·17 | 0·90 |
| Productions in tons per hour, clay . . | 13·00 | 8·00 | 4·00 | 2·00 |
| ,, ,, ,, fired body . | 6·00 | 3·50 | 2·00 | 1·00 |
| Horse-power employed . . . . . | 25 | 18 | 10 | 6 |
| Weight in tons . . . . . | 7 | $3\frac{3}{4}$ | $2\frac{1}{2}$ | $1\frac{1}{2}$ |

**66. Ball Grinders** act at the same time by blow and by crushing. They consist of a framework containing a certain quantity of balls of different sizes (Fig. 9). The interior of the framework is formed of perforated slabs placed like the steps of a staircase, on which the balls roll and fall. The material is introduced at the centre of the framework, the pieces which are sufficiently broken pass through the holes of the perforated slabs, then fall on the exterior ledges, which are covered with gauze to sift the desired size. Those portions which are too bulky to pass through the sifter fall again into the framework in consequence of its rotating movement.

These machines are used chiefly for grinding and pulverising of hard materials.

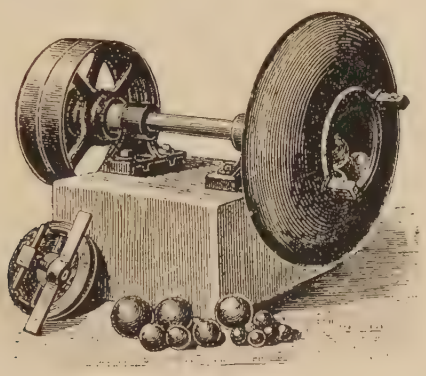

FIG. 9.—Ball Disintegrator.

Here are a few reports on the different models :—

| | | | | |
|---|---|---|---|---|
| Length (feet) . . . | 12·30 | 9·80 | 8·20 | 8·20 |
| Width ,, . . . | 8·20 | 7·81 | 6·56 | 3·54 |
| Horse-power employed . | 12 | 8 | 4 | 1·5 |

For small productions the grinder shown in Fig. 9, constructed by M. Dalbouze, can be used. This has a diameter of 19·7 to 31·5 inches for a width of 4·8 to 6·5 inches, and makes from forty to fifty revolutions per minute.

Among grinders of this kind we can also mention the Morel Mill, fixed horizontally, which revolves with great speed, and only employing a small number of large balls which act chiefly by their centrifugal force. This machine is but little used in ceramics. It is on the same plan as the Carter Mill sometimes

used in England, and as the Cyclone Disintegrator of American origin.

**67. Chopping Machines.**—Chopping machines or Blake Grinders are used to break hard materials of large dimensions. They are employed frequently to grind summarily blocks which are too large to be able to be placed directly in certain other grinders. They consist (Fig. 10) of a fixed jaw, A, and of a movable jaw, B, which can oscillate on a shaft, C. The movement is given by an eccentric wheel, D, mounted on an horizontal shaft, E, provided with two fly wheels and put in motion by a pulley. This eccentric wheel in its slight vertical displacement causes two cranks, E and F, to move away or approach; the first of these is supported by a

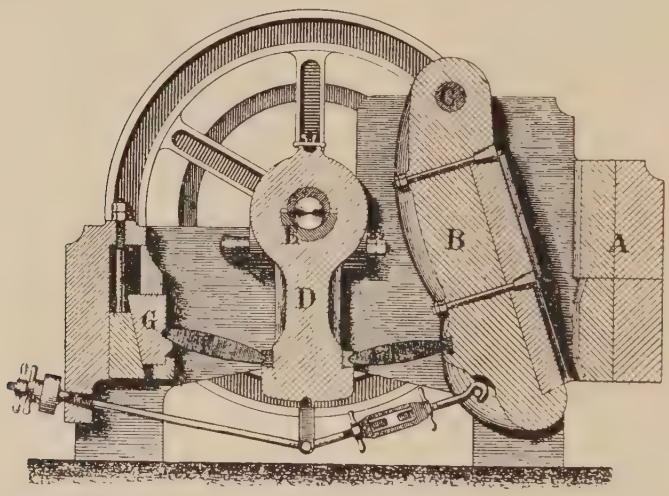


Fig. 10.—Disintegrator.

prop, C, regulated at will, and the second gives a slight oscillation to the jaw, B. A lower layer causes the latter to return to its original position.

The interior surfaces of the jaws, which are the only parts subjected to a rapid wear and tear, are of hard brass, or of steel, and prepared so as to be replaced with ease.

Chopping grinders of English origin are now mauufactured by a great number of makers. They generally have a speed of from 200 to 250 revolutions per minute.

The various current models are described according to the

measurements of the upper opening of the jaws. Here are some figures relating to them :—

| | | | | | | |
|---|---|---|---|---|---|---|
| Opening of the jaw, inches | 23·62 by 15·75 | 19·69 by 9·10 | 15·75 by 7·87 | 11·81 by 7·50 | 7·87 by 4·85 | 7·50 by 3·94 |
| Productions of cubic feet per hour | 352 | 212 | 148 | 106 | 70 | 52 |
| Horse-power employed . . | 14 | 10 | 7 | 5 | 2 | 1·5 |
| Weight in lb. . . . . | 42·98 | 21·63 | 13·60 | 9·81 | 4·46 | 4·01 |

**68. Vertical Mills** are frequently used in ceramics, because, with the exception of humid clay, they allow of the grinding of all materials. They only require slight speed, employ little force and have little wear and tear. They generally consist of two rolls mounted on the same horizontal shaft, revolving on a slab pierced with holes of the measurement of the pieces it is desired to obtain.

Sometimes this slab is solid and the material ground is removed by means of scrapers, or by a chain, but this arrangement, employed more especially for pulverisation, will be mentioned in connection with the preparation of bodies by the dry method. The weight of the rolls is caused to vary according to the hardness of the materials to be ground. When it is important that the ware should be exempt from all trace of iron, the mills, as well as the slab, can be of hard stone.

There are two types of vertical mills; in one the rolls are movable and the slab fixed, in the other the slab is movable and the rolls fixed.

Fig. 11 represents vertical mills of the first type constructed by M. Jannot. They are worked by a toothed wheel, placed in the upper part of the vertical shaft, which involves them in its rotating movements, while allowing the rolls to rise in order to pass above the pieces which are too hard or too numerous, thanks to the articulation of their shafts, round the horizontal iron pins. Scrapers of various forms bring the materials which are insufficiently ground below the rolls and separate the parts which have a tendency to agglomerate on the slab. The ground materials which have passed by the orifices of the slab are gathered in a tray, or by an endless screw. The diameter of the hollow slab is of 8·53 feet, the weight of the rolls for materials of moderate hardness should be about 1 ton. The

weight of this machine is of 3¾ tons, the force expended 3 to 4 horse-power.

In certain cases the command of the motive shaft can be carried on from the lower part. This arrangement is represented by Fig. 12. The two rolls have their shafts jointed so as to be able to raise themselves independently of each other, and the scrapers are arranged as in the preceding grinder. M. Jaeger gives the following indications on machines of this kind:—

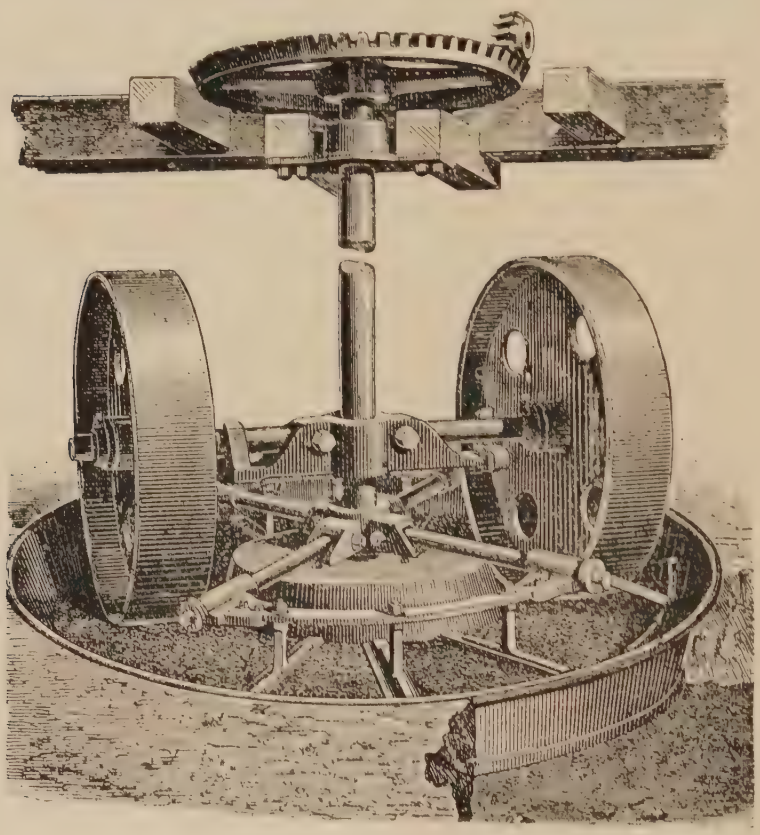

Fig. 11.—Vertical Roller Pan Mill.

| | | | | | |
|---|---|---|---|---|---|
| Diameter of the mills . . | 1,500 | 1,230 | 1,000 | 800 | 650 |
| Width of mills . . . | 375 | 320 | 350 | 200 | 160 |
| Produces lb. per hour . . | 3,350 | 2,234 | 1,117 | 558 | 224 |
| Horse-power employed . . | 8 | 5 | 3 | 2 | 1 |
| Weight of a mill . . . | 2 ton 16 cwt. | 1 ton 15 cwt. | 1 ton | 11 cwt. | 6 cwt. |
| Total . . . . . | 12,500 | 7,500 | 4,500 | 3,000 | 1,450 |

Mills with movable slab are little used in Europe as grinders. They seem to be more in vogue in the United States. Fig. 13

represents a machine of this kind constructed by Messrs Chamber Bros. & Co.

As in the preceding grinders, the slab is perforated, and the fixed rolls can in the meantime be displaced vertically by regulating themselves on the thickness of the layer of material to be pulverised in order to avoid ruptures. Fixed scrapers separate the parts which have become agglomerated and bring them under the rolls. The production of this apparatus does not differ

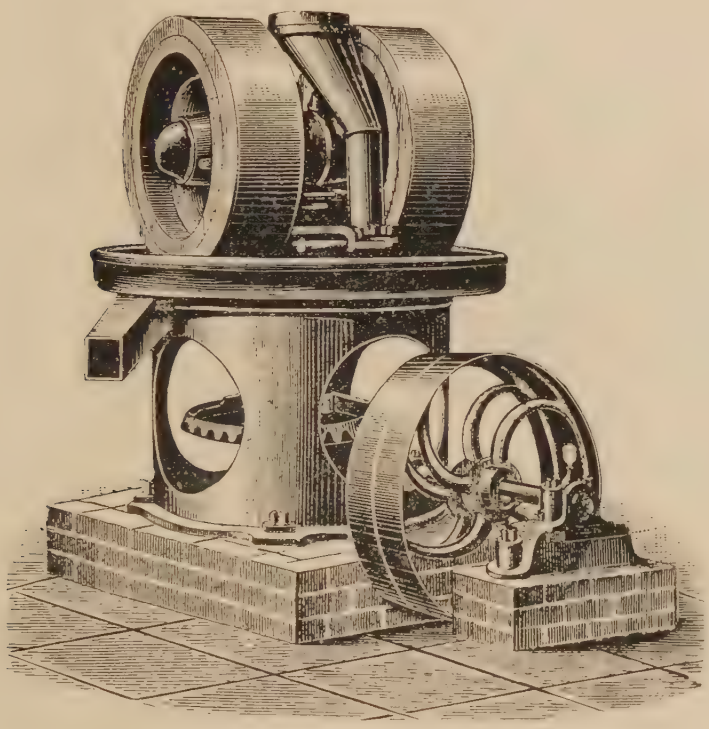

Fig. 12.—Vertical Roller Mill.

from the preceding; it is of a more complicated construction, but occasions less dust.

**69. Rolling Grinders.** — Although rollers lend themselves fairly well to the grinding of hard materials, they are only employed in ceramics to divide the clods of clay when natural disaggregation cannot be employed for this end. These rollers should be of a sufficiently large diameter to enable the clods to be seized, each turning at a different speed, so as to add to the force of crushing a force of rubbing to pieces. The separation of

the rollers ought to be able to be regulated fairly easily, and it is well to include in the construction some ledges, some breaking pieces, which support the blow, and break, while preserving the rest of the mechanism in the case where a piece of exceptional hardness would fall into the rollers. India-rubber pads or forcible springs can also be used. Scrapers are arranged below the rollers to separate the clay which adheres to them.

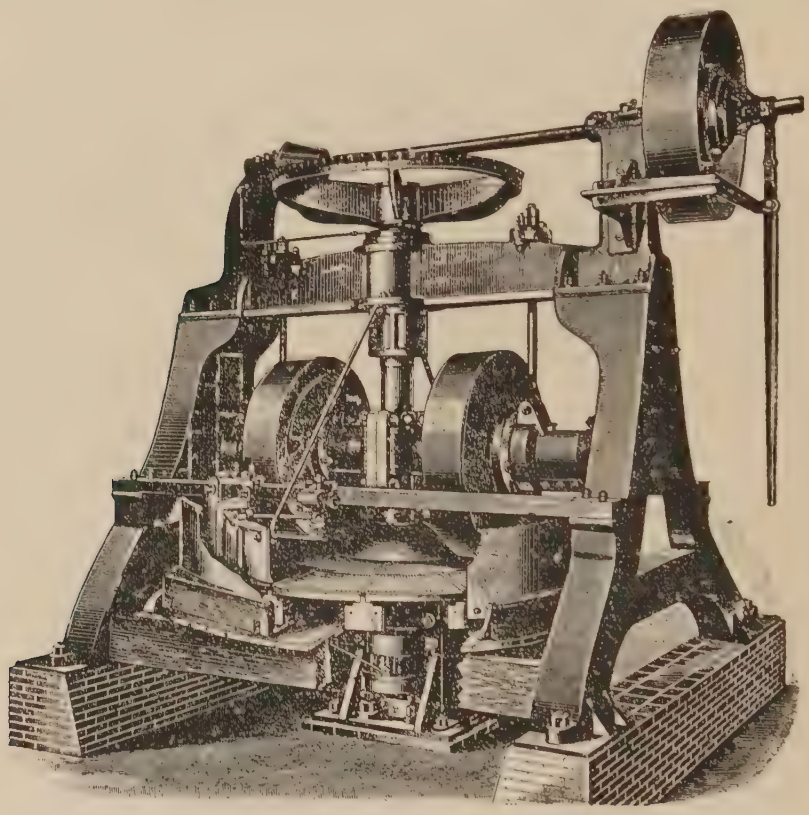

Fig. 13.—Vertical Roller Mill.

Rollers are often plain, such as that shown in Fig. 14, which represents a grinder constructed by MM. Boulet & Cie. Other times they are fluted, or have projecting parts in order to seize the clay better. They can also be toothed as in the machine of M. Schlickeysen.

For very difficult, very impure clays, it is not sufficient to make them pass through a single pair of rollers, it becomes necessary to grind them several times by successive rollers.

These cases are fortunately rare, and when they do occur it is better to employ another raw material, or to have recourse to another process of disaggregation.

Below are some numerical indications on roller grinders :—

| | | |
|---|---|---|
| Diameter of rollers (inches) . . . . . | 15·75 | 39·37 |
| Width of rollers ,, . . . . . | 15·75 | 27·56 |

Production from 176 to 362 cubic feet in 10 hours for small models.
,, ,, 1,400 to 1,750 cubic feet for large models.
Force employed from 2 to 3 horse-power for small models.
,, ,, 8 to 10 horse-power for large models.

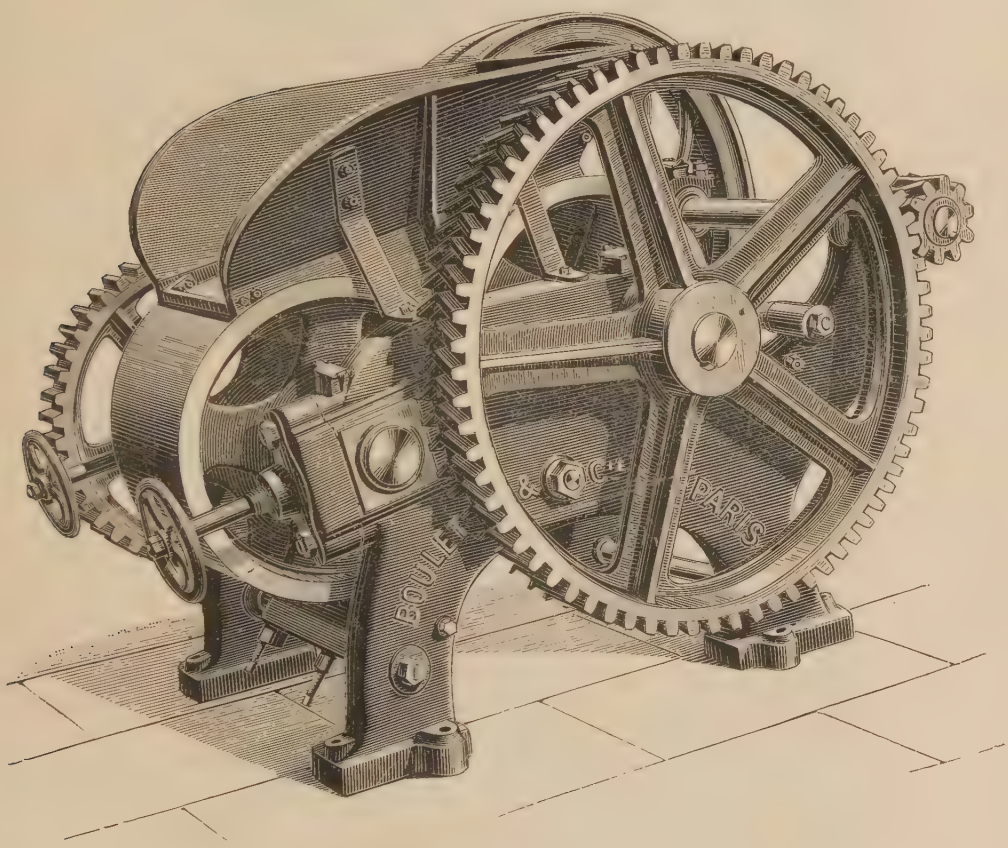


Fig. 14.—Roller Crusher.

**70. Cutters.**—Cutters are only employed for clay, or for very friable substances. They are formed of discs impelled by a fairly high speed of rotation, in which are fixed plates forming knives, against which are placed the materials to be cut. The shavings removed pass by the openings pierced in the disc, over against the knives.

When the clay is in the form of large compact and heavy clods, the disc of the cutter is placed vertically, and these clods are caused to arrive laterally by means of an inclined passage, so that they descend and are caused by their weight to lean against the disc.

When, on the other hand, which is most frequently the case, the clay is in pieces of less considerable size, it is better to make the disc turn horizontally. The material to be cut then rests with all its weight on the disc, and a cross beam prevents it from being carried away by the rotation movement.

According to the indications of MM. Boulet & Cie, a machine of this kind, having eight knives, a total weight of about 22 cwt., and making 150 revolutions a minute, cuts from 4 to 6 cubic metres per hour, using a force of 2 horse-power.

**71. Granulators.** — The object of granulators is to divide moderately plastic or open clays into small pieces. This kind of machine is especially used in America. Fig. 15 represents a granulator constructed by Messrs. Chamber Bros. & Co. It consists of an inclined plane, at the bottom of which is a beam provided with knives arranged spirally. The clay, being placed in a tray by the side of the mechanism, is cut and pushed at the same time until it falls granulated at the upper end of the plane. The mechanism is inclined more or less according to the size of the grains which it is desired to obtain. These machines cause a very large production; they can granulate from 3,525 to 7,050 cubic feet of clay per day.

### (*b*) *Purification.*

**72. Processes of Purifying.**—The processes of purifying raw materials used in ceramics are the following:—

(1) Sorting, nearly always done by hand, very rarely by machines, which enables the coarse impurities to be removed when they differ sufficiently from the material to be purified by their form, colour, coarseness, or density.

(2) Sifting, by which the coarsest parts are separated from the finer, which penetrate it as the former remain on the sieve.

(3) Washing, that is to say, separating by means of diluting in water the parts which remain longest in suspension in water

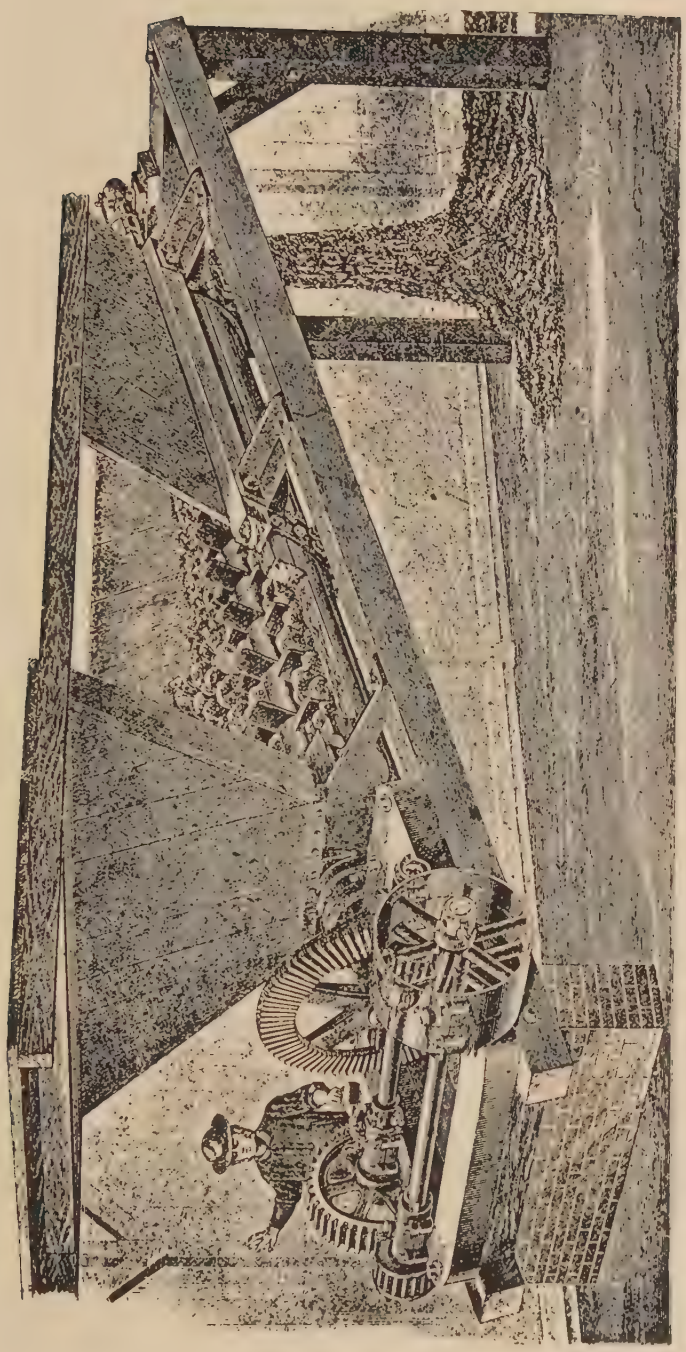

Fig. 15.—Granulator.

from those which settle more rapidly. In the levigation of clays the object is to eliminate the materials which settle first; however, in the levigation of sands, quartz, feldspar, etc., it is the parts which remain in suspension which must be removed.

(4) Ventilation is a process having the same object as levigation, but the water is replaced by a fairly strong current of air. This process, besides being rarely used, can only be applied to certain clays.

(5) Electrical purifying, in certain cases, enables a part of the oxide of iron to be cleared away which raw materials can contain.

(6) Chemical purifying, in certain cases, produces, by the action of certain substances, the elimination of injurious parts which can be found in clays, or their transformation into inert bodies.

**73. Sorting.**—Manual sorting is very much employed for separating the coarse impurities which raw materials can contain. This operation is generally carried on in the place of origin, or in its proximity, by women and children.

It is usually employed on a large scale for raw materials of value, such as kaolin, feldspar, etc. It is then only a preliminary purifying, afterwards being completed by levigation. On the other hand, for common raw materials such as ordinary clays, sands, etc., it can only consist in the elimination of some coarse impurities, stones, pellets, minerals, or roots, which is done by workmen who make the extraction.

Sometimes mechanical separation is made of stones and the coarsest hard bodies which certain clays, which are sufficiently open, can contain, by making the latter pass into conical rolling machines.

While the clay is flattened, the impurities which are rather coarse remain above in order not to be seized by the roller machines, and in consequence of the difference of circumference and speed are displaced and begin to fall.

Fig. 16 represents a purifying machine of this kind constructed by Messrs. Brewer & Co., which has found some application in the United States. It is seen that, in order to facilitate the separating of stones, the builder has placed perpendicularly to the rolling machine a wheel provided with points, which seize them

into an inclined trench, but this supplementary arrangement is not indispensable. The good working of purifying rolling machines depends greatly, as it has just been observed, on the nature of the clay, and it is also essential to accommodate the diameters, the "conicity" and the separation of the rolling machines well to the dimensions of the stones to be eliminated.

**74. Sifting.**—In ceramics three kinds of sifting can be distinguished, having different objects.

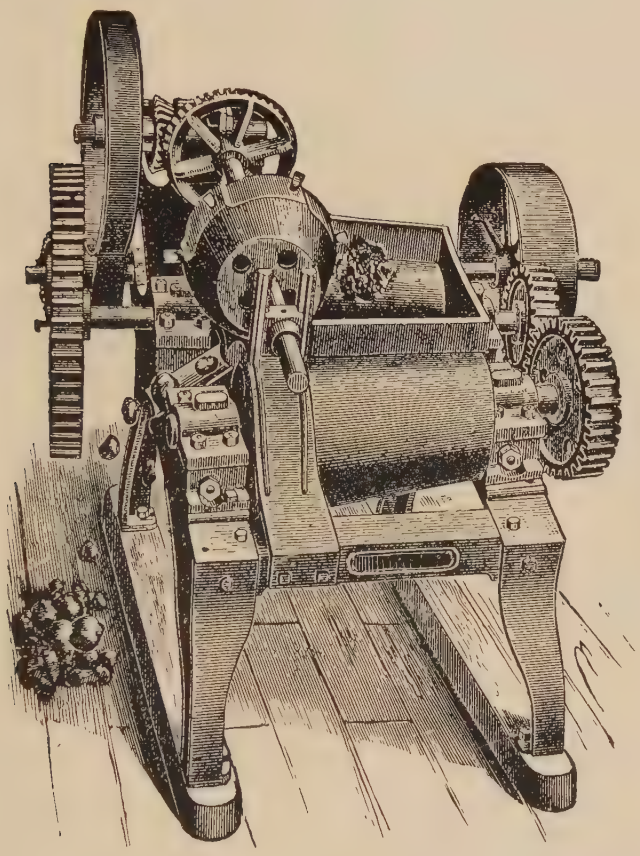

Fig. 16.—Roller Separator.

(1) The sifting of dry pulverulent materials, which is generally a complementary operation of grinding or pulverisation, and not a purifying properly so called. It is only exceptionally that dry clays can be sifted in order to remove the coarse impurities which they can contain. This work is performed then on screens, or in sieves used for sifting sand. It offers no other peculiarity worth mentioning.

(2) Sifting of liquid materials, which takes place in the course of purifying by grinding, as well as that used in the preparation of bodies by liquid method, which will be mentioned when describing these operations.

(3) Sifting of pasty materials, that is to say, of clay in the plastic form. This operation is performed by compressing the clay to be purified into a box, and by forcing it out by orifices of suitable dimensions, while the coarser impurities remain in the interior. On this principle various apparatus have been constructed, which differ only in the nature of the force employed and the mode of transmitting it.

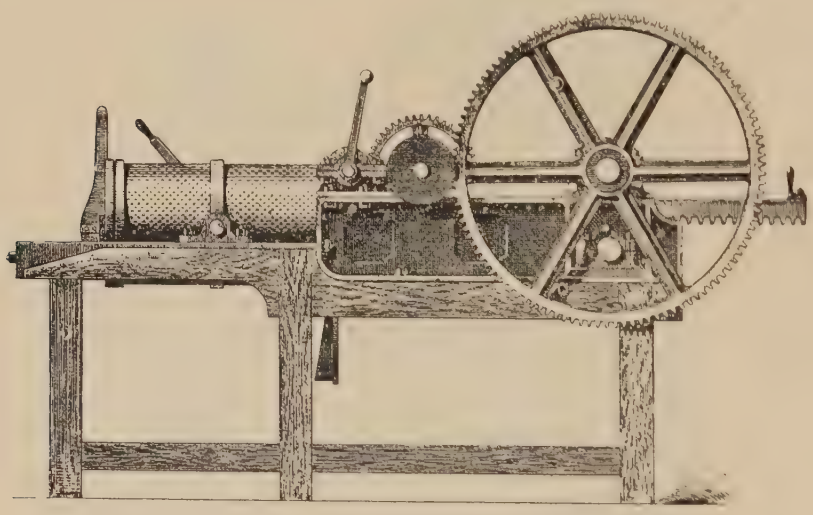

FIG. 17.—Clay Separator.

Fig. 17 represents a purifier constructed by M. Chambrette. It consists of a cylinder perforated with holes, movable round an horizontal beam, and of a mechanism intended to work the compressing piston.

The perforated cylinder being placed vertically, it is filled with clay, then placed horizontally, and by means of a handle acting by two intermediary beams the workman forces the piston to penetrate into the cylinder, compelling the clay to make its exit by the holes, while the stones remain at the base. When the piston has reached the end of its course, one of the pinions is unfastened, and the piston is brought back again rapidly by working a second handle fixed on one of the arms of the large

wheel. The cylinder is then placed back again vertically, and the bottom of it is opened to cause the stones to fall which have accumulated in it. In spite of the apparent complication of this arrangement a man can with this machine purify from 140 to 175 cubic feet a day.

Fig. 18 represents an analogous purifier constructed by M. Groke. In this case the compression box is triangular in form and the circular orifices of the sieves are replaced by parallel sheets, more or less close together, mounted on hinged doors. A fly wheel with levers enables a triangular piston to descend or

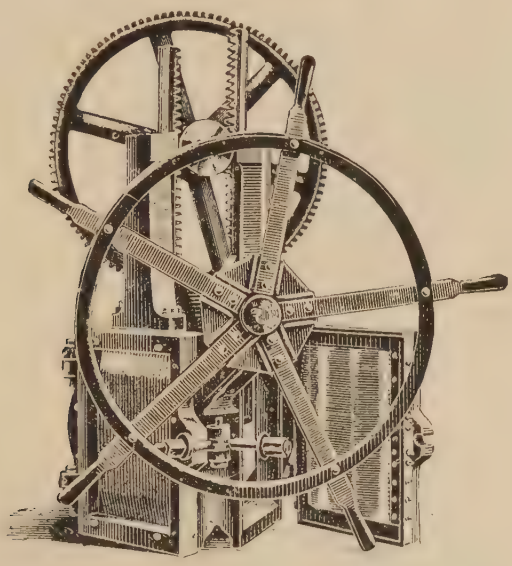

Fig. 18.—Clay Separator.

to rise. The operation is carried on in the same manner as in the preceding machine.

In order to obtain a larger production, it was natural to substitute for the action of a man that of hydraulic motive power, and this is what M. Chambrette had done in the machine represented in Fig. 19. Two cylinders, perforated with 1,500 to 1,800 holes, are movable round one of the uprights of an hydraulic press, one of them being loaded while the other is under pressure. This machine can purify 560 to 700 cubic feet of clay in ten hours; the total amount of effort exercised on the piston is about 10 tons.

All the preceding machines act in an intermittent manner. The operation can be carried on also in a continuous manner by making use of a screw propeller, but in this case only those

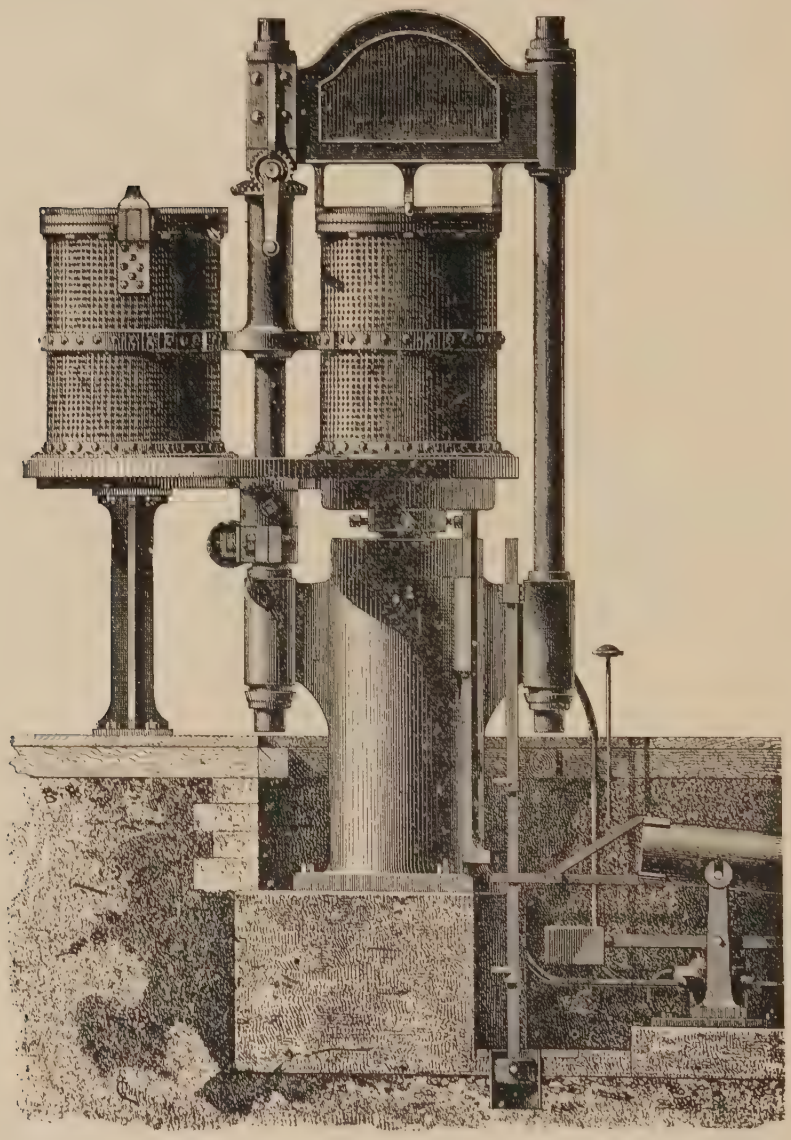

Fig. 19.—Clay Separator.

clays can be purified which are in the form of a fairly soft body. Fig. 20 represents an arrangement of this kind adopted by M. Brethon (Delahaye, successor). The clay loaded at the

upper part of the vertical cylinder is compressed towards the lower by spiral pallets, and is compelled to pass through the holes which are perforated in the bottom of the cylinder. Above this sieve is moved a pallet, which drives the stones remaining towards the two lateral walls, whence they can be removed gradually by opening one of the movable panels from time to time.

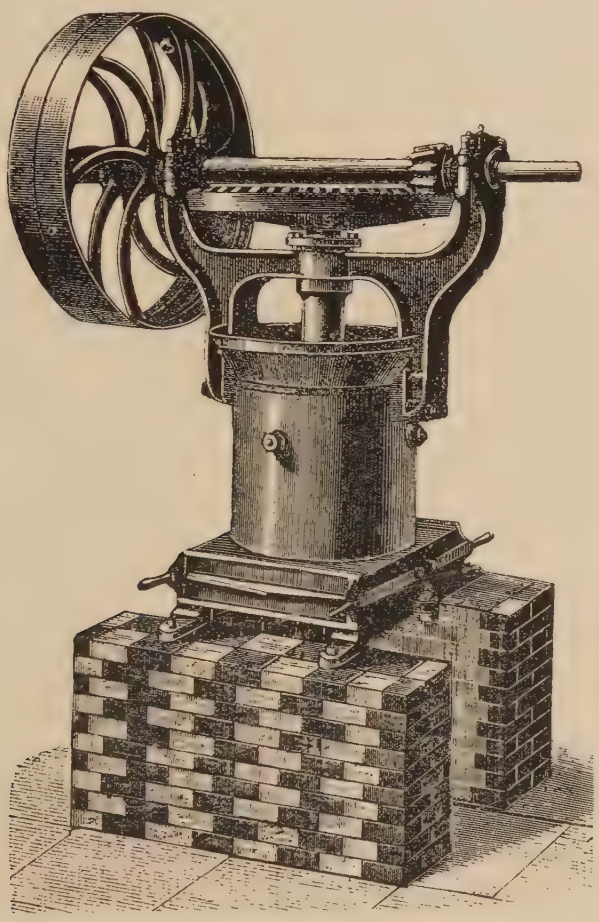

Fig. 20.—Clay Separator.

Purifying can also take place in a continuous manner by making use of a pair of rolling machines as propellers, which compress the clay into a box closed by two movable panels carrying the sieve, which consists of steel meshes parallel to each other. The separation of these threads ought naturally to be slighter than that of the rolling machines in order to retain

the pieces of stone broken by the latter. From time to time the panels are opened in order to allow the stones to make their exit. A machine of this kind is constructed by the firm of Smidth & Cie.

It is well to remark that in order that any of these systems of purifying should work suitably, the clay must be in the form of a sufficiently soft and plastic body. If therefore it is not found naturally in this condition, which is most frequently the case, it must be preliminarily prepared by one of the processes mentioned later on, in the article referring to the preparation of bodies.

**75. Washing of Clays.**—The object of washing is to separate the coarsest and heaviest parts of clay, which settle rapidly, from the finer and lighter parts, which remain longer in suspension in water. As it has already been observed, when treating of the trials of raw materials, all the impurities are not thus removed from the clay, but only the coarsest are eliminated, while those which are frequently in the form of very fine powder, such as sand, carbonate of lime, and oxides of iron, remain at least partially incorporated with the hydrosilicates of alumina. On the other hand, there is complete elimination of soluble salts.

Washing is generally employed for kaolins and plastic clays used for the manufacture of porcelain ware, fine stoneware, faience and terra cotta. Its rather high cost does not permit its employment for common clays, which are used for the manufacture of terra cotta for building purposes, except in those countries where no sufficiently pure clays are to be found.

The processes of washing are rather variable, for they depend on the nature of the clays, on the degree of purity which it is requisite to obtain, and on the importance of the production. However, whatever the method employed, it necessarily includes three stages:—

1. Blunging of the clay in water.
2. Separation of the grit and sand.
3. Placing of the clay in decanting tanks.

These different operations will be dealt with in order.

**76. Clay Blungers.** — Open clays and kaolins are easily

blunged in water, and they can be subjected to washing when taken from their place of origin. In plastic clays the operation is more difficult, and it is usually necessary to disaggregate them previously by one of the processes described above. Natural or artificial drying is the one most employed, and is the most efficacious.

When small quantities of clay have to be ground the blunging can be done manually by placing a certain quantity of clay in vats filled with water, and agitating it by means of rakes and paddles moved by one or several workmen. When all the clay is suitably blunged, it is poured into settling tanks through an orifice placed a little above the bottom of the vat, in front of which is placed a grill which retains the grit. This operation is repeated several times, until the deposit of grit has reached the height of the grill; it must then be removed by a shovel and the vat cleaned.

For open clays, kaolins, and when a large quantity of water may be used, they can be blunged hydraulically, by being subjected to a jet of water under pressure, which disaggregates the clay, carries away the fine parts and leaves the grit. For this object the clay can be placed in a vat which is refilled from time to time, the portion blunged flows away in a continuous manner, the operation only being interrupted when it is necessary to remove the grit accumulated in the vat. For the washing of kaolins containing stones of large size the hydraulic method is also empolyed in Cornwall, but the rock in its place of origin is attacked directly by means of powerful jets of water. The stones accumulate in the shallow water of the course, whilst the water which carries away the clay is conducted into large basins.

Besides these special cases, blunging is done mechanically. There are two kinds of mechanical blungers.

Those with a vertical shaft are used in preference for open, stony clays, and those with a horizontal shaft are used more for blunging plastic clays which are slightly pebbly.

Fig. 21 represents a machine of this kind for medium outputs. In a circular vat works a central vertical shaft, carrying two wooden arms, agitated by a rotatory movement. From time to time a certain quantity of clay, and a corresponding volume of water, are poured into it. The flowing of the blunged

clay is either continuous or intermittent, by opening one of the wooden stoppers which close the orifices of egress placed laterally in the vat at different heights. The gritty substances accumulate at the lower part, and can, according to their consistency, be removed by hand from time to time from above, or by a lower clearing orifice, causing at the same time a running

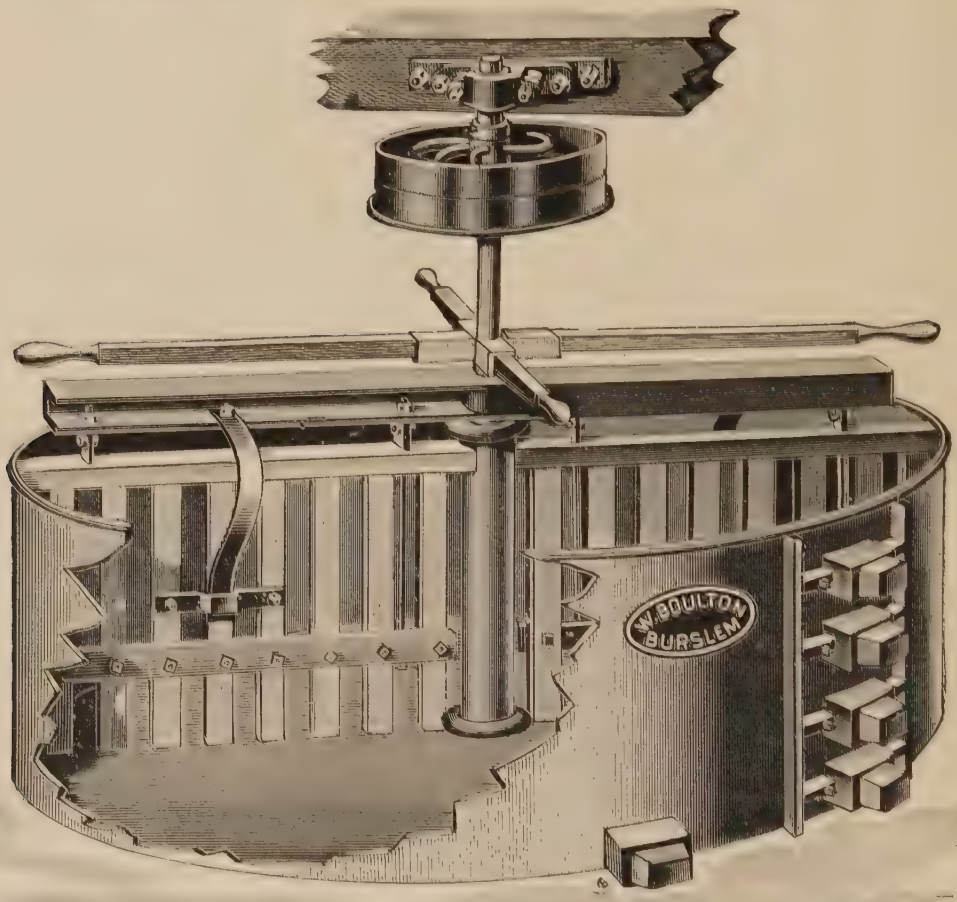


Fig. 21.—Blunger.

stream. It frequently happens that when the working of the blunger is stopped for some time the clay in suspension settles and forms with the grit a fairly hard mass, which can break the spikes when put in action. In this case it is expedient to first disaggregate this mass by first turning the blunger by hand by means of the levers shown in the drawing.[1]

[1] In England this mill is usually employed for milling Cornish stone and flint.—W. P. R.

For large productions, and particularly for clays which are very stony, the blunger shown in Fig. 22 is used. It consists of a circular stonework trough, in which two or three wooden bars, suspended by chains, are worked. As with the pre-

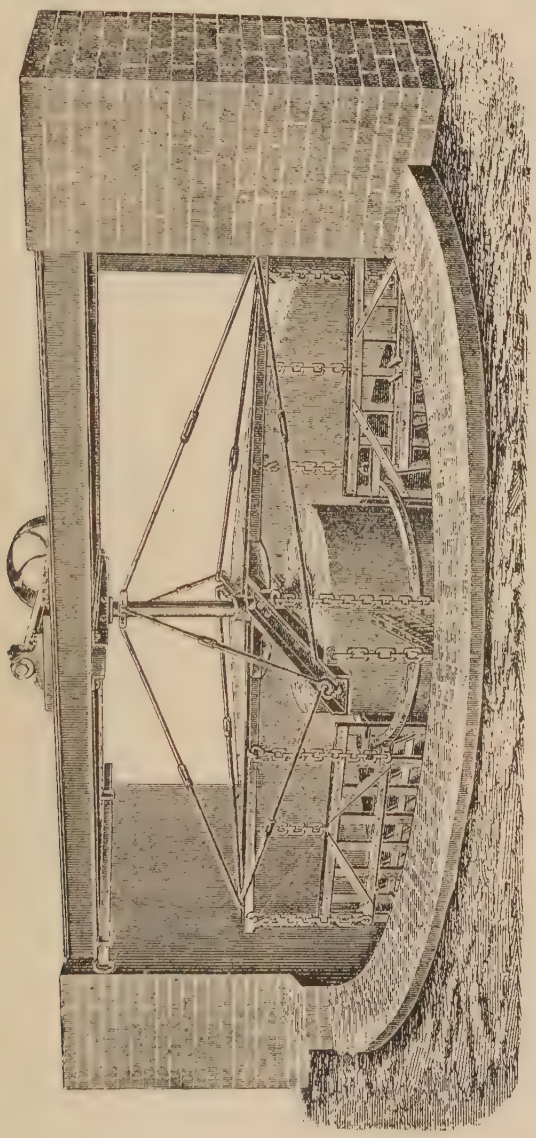

Fig. 22.—Wash Mill.

ceding machine, clay and water are introduced at regular intervals, the blunged clay flowing continuously by an orifice provided with a grill, placed at a short distance above the trough, and acting as a dam. The grit accumulates at the

bottom, and, in proportion as the thickness of its layer increases, the height of the chains decreases, thus raising the harrows. This manner of flexible suspension has, moreover, the advantage of avoiding any rupture at the time of unmooring. It has often been tried to render the working of these blungers absolutely continuous by removing the grit and stones during action by means of cup chains, or Archimedean screws. But the advantage which results therefrom is largely counteracted by the continuous repairs needed for these machines. It is better to proceed every ten or fifteen days to a clearing, which indeed is often difficult enough, in consequence of the agglomeration of the grit.

The proportion of water used in these blungers varies from two to three times the weight of the clay. Their output depends entirely on the tenacity of the latter and on the force

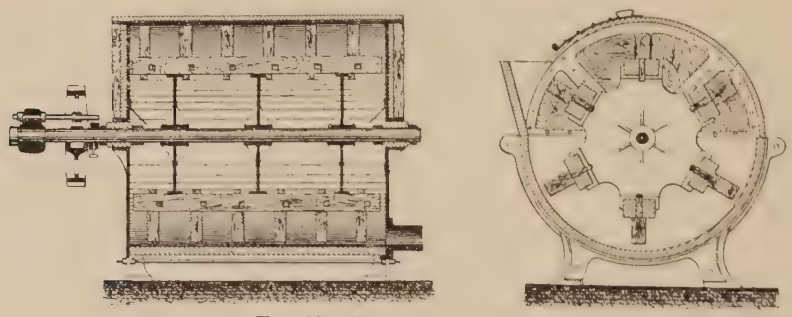

Fig. 23.—Horizontal Blunger.

expended. For medium outputs the hand can be used, but for large outputs a mechanical propeller is necessary. In this case the quantity of clay washed can amount to 1,760 and even 2,550 cubic feet in twenty-four hours.

Blungers with an horizontal shaft are formed of a framework in which this shaft, provided with pallets, is worked. Either the framework can be made to turn, the shaft being fixed, or the shaft with the pallets is turned inside the immovable framework, or, finally, both can be made to move in an opposite direction. The arrangements for the entry of water and clay, as well as the egress of the blunged clay and the grit, are also variable and have aroused the ingenuity of constructors. The two following are only given as examples.

Fig. 23 represents a blunger with fixed framework in which

is worked a shaft, carrying, by means of three sheet-iron discs, six wooden crossbars, on each of which are placed six pallets. The clay is introduced by a lateral hopper, which is then closed by a cover to avoid projections of water.

The draining is done in a continuous manner by a lower pipe, the clay and sand are also removed by the water, the apparatus only being suitable for clays which are not very stony. The dimensions of these blungers can vary from 6½ feet to 22½ feet in width, and from 3·28 to 9·85 feet in diameter. The speed of rotation is from 15 to 30 revolutions a minute, the force expended is from 1 to 3 horse-power, and the amount of work done from 175 to 875 cubic feet of clay washed per day.

In the blunger constructed by M. Schmelzer, the clay is introduced in a continuous manner by a shovel, at the same time as a small quantity of water, into the first case on the left containing a kind of plug mill mounted on a horizontal shaft. The clay is there disaggregated, then passes in the form of a pasty substance into a neighbouring box, where it is blunged with a large proportion of water. From there it falls into a sifting framework which allows the clay to pass as well as the blunged sand, while retaining the gritty substances and bringing them to the extremity of the apparatus, where they fall into a hopper. The work done by this blunger varies from 180 to 750 cubic feet per day, according to the size of the apparatus and the nature of the clay.

**77. Sand Separators.**—It is seen that in all the preceding apparatus the stones and grit which the clay can contain remain in the blunger, or are there separated from the other parts carried away by the liquid current; generally a sieve at the egress of the apparatus regulates the maximum size of the grains removed at the same time as the clay. Sometimes this purifying is sufficient, and the liquid going out into the settling tanks is made use of directly, but more often it is expedient to eliminate more or less completely the sand carried away.

In order to obtain this result it is sufficient to diminish the speed of the liquid current more and more. The arrangements adopted for this object depend on the degree of purity which it is desired to obtain, and on the production.

For small quantities it is sufficient to make the liquid going out from the blunger flow into a tank, where it is allowed to remain in tranquillity for a greater or less length of time according to the degree of purity to be obtained. The surplus liquid is then sent into settling tanks.

For large productions the separation is carried on in a continuous manner, by causing the liquid to pass out from the blungers into stonework channels coated with cement, or into wooden trenches, the section of which goes on increasing. Fig. 24 represents a sand separator of this kind in stonework and sunk into the ground. The sand which settles at the bottom

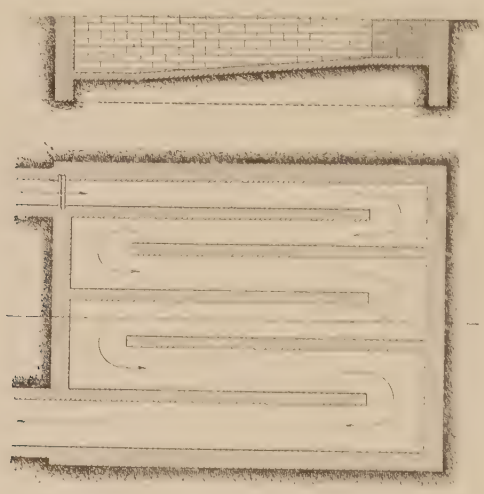

Fig. 24.—Sand Separator.

of the pipes is removed by a shovel generally every twelve hours. It can be got rid of by means of a stream of water.

Fig. 25 shows another arrangement of sand separators. In the latter circulation takes place in the wooden trenches, leading every 10 or 13 feet into casks, at the bottom of which the sand settles, and should be removed by hand as they become full. The length of these trenches and the number of the casks naturally depend on the degree of purity it is desired to obtain.

**78. Settling Tanks.**—Whatever may be the process, if blunging and the sand separator is adopted, the liquid holding the clay in suspension is finally sent into the tanks, where, by means of absolute tranquillity, all the solid parts settle. For clays intended for the manufacture of fine wares it is expedient to use several

settling tanks of limited dimensions, which are filled successively and in which the mass deposited is homogeneous. For the manufacture of ordinary fired bodies tanks of large dimensions can be used, in which the deposit is much less homogeneous, the most sandy parts naturally depositing themselves near the orifice of entry of the liquid.

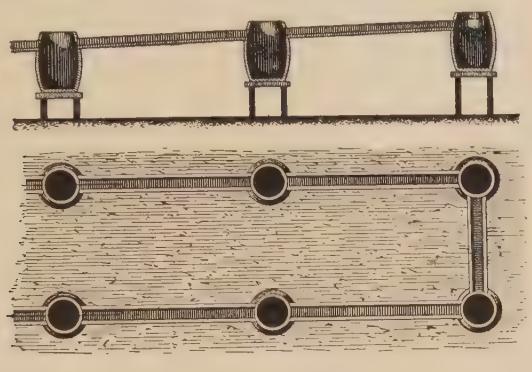

FIG. 25.—Sand Separator.

In all cases these tanks are provided with lateral orifices at different heights, which allow the pure water to flow, which floats at the end of a given time of tranquillity. For this same a pipe can also be used, which can be more or less inclined, as is shown in Fig. 26. When all the surplus water has been removed the clayey mass is still too soft to be used; it is necessary to allow

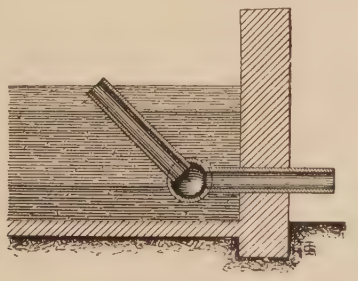

FIG. 26.—Decanting Tank.

it to be stiffened by slow evaporation, which is certainly the most tiresome operation of levigation, for it requires much time and takes up considerable space. It has been tried to shorten it by means of decanting tanks, called filtering tanks, the base of which is formed by a layer of sand in which are placed drain pipes. This arrangement acts very well at the

beginning, but the sand and the pipes rapidly cause an obstruction. Nevertheless the small amount of water which always continues to flow ought to make filtering tanks preferable to tanks with an impermeable base.

For small productions one can hasten the stiffening of the clay by removing it from the tanks and placing it in small heaps which dry in the sun. Filter presses can also be used for the same purpose, and these will be described when dealing with the preparation of bodies by the liquid method.

Generally settling tanks have a height of 3 feet 3 inches, corresponding to a deposit of clay from 8 to 12 inches in thickness. But it must be remembered that this clay, which is deposited in successive layers, is not homogeneous, the most sandy parts being the first to be precipitated. It is expedient, therefore, to remove it by vertical channels in order to have a fairly regular composition.

In all these installations of levigation of clays, it is necessary, as far as possible, to make use of natural variations of level, or to raise the clay to be washed to the highest point, the decanting basins being, on the other hand, at the lowest part. If this programme cannot be carried out, recourse must be made to elevator apparatus, such as endless chains, norias, etc. When the sand is in small proportion and very fine, pumps with simple working piston and spherical valves can also be used for great heights.

**79. Levigation of Sands.**—In the levigation of sands and other antiplastic materials two objects are in view :—

(1) To remove the earthy materials which can pollute them, and this is generally the case.

(2) To separate the coarsest parts in order to obtain a fine homogeneous material.

In the first case the different clay blungers described above can be employed. If the materials to be washed are coarse, they remain in the blunger, and are drawn out when the water departs clear. If, on the contrary, they are fine they are allowed to flow into some decanting basins from which the thick surplus water is then removed. The stiffening takes place very rapidly, and offers none of the difficulties which are met with in the clay.

The same process allows the separation of the coarse parts of sands, and of classifying the latter by grains of decreasing sizes. For this object it is sufficient to place two or three basins of small dimensions, inclining one on to the other, and in which are placed the various sorts of sand.

**80. Ventilation.**—By directing a violent current of air on to pulverised materials they are placed in suspension in the air, as they would be in water. If the speed of the current is then diminished the coarsest parts settle first, then the finest, and finally the impalpable powders only fall when the speed is stopped. Ventilation, therefore, acts in the same way as levigation, and it is understood that in certain cases it can replace it.

Up to the present, however, this process has been but rarely employed, and only for the purifying of kaolins. The latter, in consequence of the notable difference of weight which exists between clay and rocky powders, lend themselves best to this method. The kaolin is first reduced to a fine powder by pulverisers and placed in a hopper, whence it flows by an orifice of slight thickness before the blast pipe of a ventilator. The gaseous current is then conducted into a pipe, the section of which becomes greater, and ends in a rather large chamber. The dimensions are calculated in such a manner that the parts which it is desired to eliminate settle in the pipe, and only the purified kaolin enters into the chamber. But it is rather difficult to divest the air going out from the chamber of the last traces of impalpable dust, and usually it ought to be sifted by canvas or packing, which must be beaten from time to time.

**81. Electric Purifying.**—Iron and oxides of iron can be eliminated by utilising their magnetic properties. For this purpose the material to be purified should be reduced to a powder, or placed in suspension in water, so as to give to the parts to be eliminated a sufficient mobility to enable them to be drawn by electro-magnets.

When the material is pulverised it is placed in a trough, in the midst of which the magnets are caused to turn, and they are removed from time to time to deprive them of the ferruginous particles which adhere. But most usually the process is by

humid method, by making use of the arrangement shown in Fig. 27. The material to be purified, being placed in suspension in water, flows in the form of thin sheets through a trench above which are placed the electro-magnets, traversed by a current coming from an ordinary battery. From time to time the flowing is stopped, the magnets are removed, they are placed in a trough filled with water placed at the side, and the current is interrupted so as to make the ferruginous particles which have adhered fall. This process of purifying is employed in certain earthenware and porcelain factories at the time of the preparation of the body by liquid method.

**82. Chemical Purifying.**—It is only in very rare and quite special cases that raw materials used in ceramics can be purified

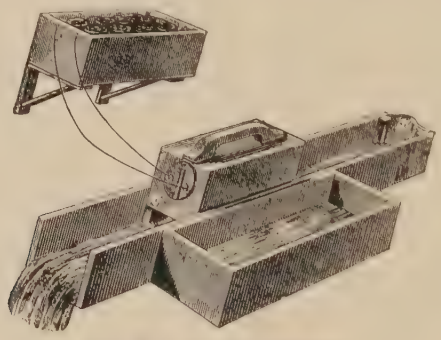

Fig. 27.—Electro-Magnets.

chemically. An ancient practice of the potter's art, the mellowing or laying of clays, appears, however, to rest on a reaction of this kind. Salvetat has admitted that under the influence of water charged with organic substances in decomposition the sulphate of lime contained in certain clays can be transformed into sulphide of calcium. This last salt, in contact with the carbonic acid of the air, is decomposed in its turn with an evolution of sulphuretted hydrogen, which is often easy to observe. Moreover, the colouring of the body in black, which is sometimes produced in this case, as well as its bleaching when exposed to air, can be explained by the formation of black iron sulphide being oxidised in the open air in order to give colourless sulphate or protoxide of iron, which is soluble in water. The result of the mellowing would be the elimination, in the

form of a soluble sulphate, of the sulphate of lime contained in the clay.

But the latter, which often produces efflorescence on the surface of terra cottas, in consequence of its relative solubility in the water of formation, can be neutralised more efficaciously by adding to the clay some salts of baryta, chloride, or carbonate. It then produces a double decomposition :—

$$CaOSO^3 + BaCl^2 = CaCl + BaOSO^3$$

or

$$CaOSO^2 + BaOCO^2 = CaOCO^2 + BaOSO^3.$$

In the first case the chloride of calcium produced is easily removed in consequence of its great solubility; in the second the carbonate of lime is insoluble as well as the sulphate of baryta, and cannot longer produce efflorescence. The use of carbonate of baryta is preferred, which is found in the trade in the form of a powder coming from the pulverisation of witherite, which contains up to 97 per cent. of this carbonate. It is essential that this powder should be very fine, in order that chemical action may be produced completely without having to add too great an excess of reagent. The proportion of witherite to be added is easily calculated when the amount of sulphate in a clay is known, but it is expedient to multiply by 1·5 or 2 the quantity theoretically necessary. Witherite is found in different parts, chiefly in the Rhine Provinces, where it is sold, in a pulverised state, at 100 to 130 francs per ton. According to the amount of sulphate of lime in bodies, the value of witherite used can be estimated from 0·10 franc to 1 franc a cubic metre of body.

It has also been proposed to remove the carbonate of lime contained in bodies by treating the latter with diluted hydrochloric acid in formation with chloride of calcium, which is got rid of by washing. This process has never been employed on a large scale.

Washing with an acidulated water will also eliminate oxide of iron, which becomes soluble in the form of a chloride or nitrate, unless the iron is in the form of silicate. In this case the silica could only be displaced by a prolonged and heated action.

### 3. Preparation of Bodies.

**83. Processes of Preparation of Bodies.**—Raw materials having been suitably disaggregated and purified, it is necessary to transform them into a homogeneous body having the desired composition and consistency corresponding to the method of formation adopted. This preparation of the bodies includes three series of operations :—

(1) Those relating to the measuring of raw materials.

(2) Those relating to the mixing together, that is to say, to render the body homogeneous.

(3) Lastly, those the object of which is to give suitable consistency to the body.

These operations can be successive or simultaneous.

The preparation of bodies is made by three different processes, characterised by the physical condition in which the raw materials are found at the time of their measuring or of their mixture :—

(*a*) Preparation by plastic method, in which the materials are apportioned and mixed in the form of bodies already having the desired consistency. According to the degree of this consistency the preparation of soft body is distinguished from the preparation of stiff body.

(*b*) Preparation by dry method, in which the materials suitably pulverised are apportioned and mixed in the form of dry powders, then moistened in order to obtain the desired consistency.

(*c*) Preparation by liquid method, in which the materials are blunged and mixed in water, then partially dishydrated in order to then give to the body the necessary consistency in formation.

The process by the plastic method is usually the least costly ; it is adopted by preference in the manufacture of fired bodies for buildings, of pottery wares in refractory bodies, of faience wares and common stoneware, especially when clays are used which naturally have the desired composition, or when the mixtures are made easily. It does not lend itself to a rigorous apportionment, and becomes laborious if it is desired to obtain perfect homogeneity.

Preparation by dry method lends itself, on the contrary, to an exact apportionment, the mixture is made easily, the grain of the body can be coarse or fairly fine at will. It is employed in the manufacture of refractory clays, of certain terra cottas for building purposes, of faience ware and common stoneware. Its one drawback is that it requires the use of raw materials which are sufficiently dry to be able to be pulverised. When the grain of the body must be very fine and the mixture absolutely intimate, recourse must be made to preparation by liquid method, more costly and more complicated than the others. This is the method used in the manufacture of porcelain ware, faience ware and fine stoneware.

### (*a*) *Preparation by Plastic Method.*

**84. Apportionment of Raw Materials and of Water.**—In the preparation by plastic method there are only two distinct operations :—

The apportionment of raw materials and of water.

The making of the body homogeneous.

The apportionment presents three cases according to the degree of humidity of the raw materials.

*Case* 1. Raw materials have naturally the desired humidity. They are placed directly in the apparatus for homogeneisation by apportioning them by volume, as for example three barrows of plastic clay, one of open clay and one of sand.

*Case* 2. The raw materials are too dry. This is the most frequent case.

If the clay is open enough and easily absorbs water it is sufficient to place on the ground, or better, on a board, some heaps from 3 feet to 4 feet 6 inches high, formed of horizontal layers of the various raw materials, to which is given a thickness corresponding to the apportionment to be obtained. Let there be, in resuming the preceding example, 15 inches of plastic clay, 5 of open clay, 5 of sand, then again 15 of plastic clay, and so on. During the formation of the heaps they are sprinkled with a hose or watering pot; then the whole is left to remain as long as possible, twenty-four hours being the minimum, so that the whole mass may have the same degree

of humidity; they are then cut vertically and brought to the pugging apparatus.

When the clay is dense and absorbs water with difficulty the process is the same, except that the successive layers are placed in impermeable pits. When the pit is filled, water is added in sufficient quantity, so that it is level with the upper part of the mass. If there is an excess of water, it can be removed by opening a bung-hole provided in the lower part. The trenches are usually 3 feet 3 inches to 6 feet deep and have a capacity of 8 to 35 cubic yards. They are made of cemented stonework dug out of the ground, or in elevation. In the latter case an aperture is made, closed by a wooden door, for the entry of raw materials and the exit of the body. The mass ought to remain a fairly long time in the pit in order that all the clay may be disaggregated, and the humidity also distributed, which takes at least twenty-four hours and at the most three days.

*Case* 3. The raw materials are too humid. This sometimes happens during the rainy seasons, or when the clay is got out from beneath the water, or when the clay has been washed. It is then necessary to procure a certain quantity of clay dried in the sun, or artificially, to pulverise it and mix it with other materials, by making use of one of the processes of apportionment described previously. When the quantity of dry clay which it is thus necessary to dry is not too considerable, it can be replaced by the dry body coming from the broken products, or products which have been thrown out of shape during the drying.

**85. Homogeneisation of Bodies.**—The homogeneisation of the body, apportioned as it has just been said, comprises two operations:—

Grinding, by which the lumps of clay, pebbles and stones are crushed; pugging, the object of which is to mix intimately all the substances which compose the body.

These two operations ought not to be considered as quite distinct, for, on the one hand, grinding rollers, especially when they are used for this purpose, partly pug the body, and, on the other hand, pug mills can perfectly divide the lumps of clay.

When the body contains neither pebbles nor grit, the grinding can be dispensed with, and pugging may be sufficient, but it is to be noted that a pug mill cuts much more, or, for an equal production, employs less force when it works on a body previously laminated. Pugging, on the other hand, is an indispensable operation for the obtaining of a homogeneous body.

**86. Grinding or Rolling.**—Grinding can only be done when a motor force is employed; small grinding rolls worked by hand are not at all efficacious. If they are sufficiently brought together for grinding stones they are stopped at each instant; if they are opened to avoid this inconvenience they serve no purpose. In small potteries it is better to purify bodies by sifting or by grinding than to endeavour to crush the gritty substances.

Rolling mills usually consist of two hard cast cylinders, being worked by means of two cog wheels, the teeth of which are arranged so as to be able to come closer together in order to counterbalance the wear and tear. Except for their dimensions, they have the same arrangements as roller grinders (Figs. 18, 19, 20). They are generally made to turn with different speeds in order to better break up the clods of clay, and they are provided with scrapers in order to detach those which adhere.

Their productions and the motive force which they require, varying with the quality of the body, can be estimated on an average as follows:—

| Diameter, inches. | Length, inches. | Production in $m^3$ per hour. | Horse-power. |
|---|---|---|---|
| 11·81 | 11·81 | 1 | 2 to 2½ |
| 15·75 | 15·75 | 2 to 3 | 3 to 4 |
| 19·68 | 19·68 | 4 to 5 | 5 to 6 |
| 23·62 | 23·62 | 7 to 8 | 8 to 9 |

When the clods of clay are too large or the stones too numerous, two or three pairs of rollers superposed must be used. In this case the upper rollers are rather apart, while the lower are put close together to the degree of fineness which it is desired to obtain. It is natural to make the latter turn more rapidly in order to allow them to cut up the same quantity of body.

The pugging produced by the rolling machines can be increased by fluting them circularly, or by giving them a conic form, the small diameter of the one being placed in front of the large diameter of the other. Some scrapers remove the body

which accumulates in each fluting. Where there is equality of production the power employed by these rolling machines is nearly double that consumed by plain rollers.

Figs. 28 and 29 represent rollers of both these kinds constructed by MM. Boulet & Cie.

**87. Pugging.**—Pugging was for long done by treading the clay with the feet on floors, or in shallow stonework pits. In certain countries this work is still carried on in the same manner, but by means of horses or oxen, which are made to turn in a circular pit. These primitive processes have a tendency

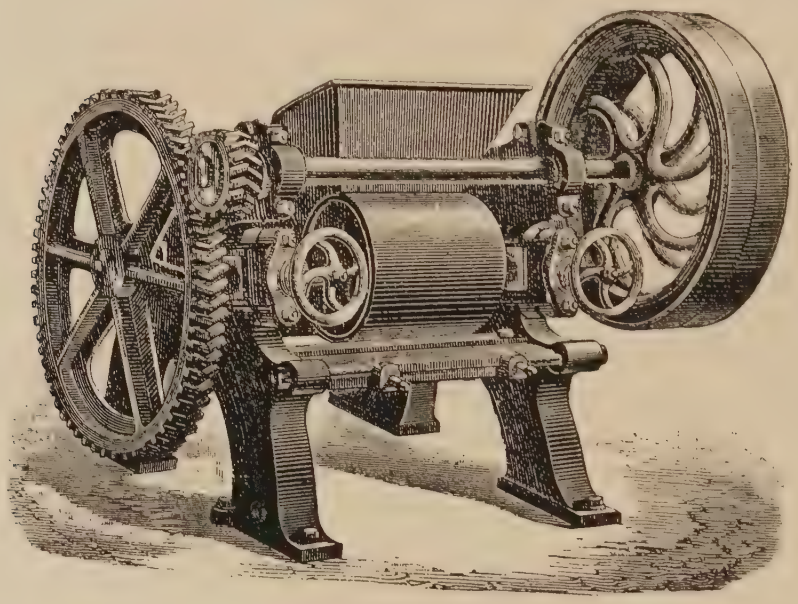

Fig. 28.—Roller Mill.

to disappear, for there is every advantage in making use of the strength of animals to work a suitable pug mill.

Pugging is now done by means of vertical or horizontal pug mills.

Vertical pug mills consist of a cylinder closed at the base, in which is worked a movable shaft carrying knives at different heights. The body is introduced by the upper part and makes its exit by means of a lower opening which can be regulated at will.

Fig. 30 represents a machine of this kind, worked by a pulley and a double set of wheels. When a soft body which is but

little plastic is worked upon, a single set is sufficient. Sometimes the transmission of movement takes place from the lower part; unless under special circumstances this arrangement is not to be recommended. For a small production the motive force can be replaced by manual labour, in which case the driving shaft is fixed directly on the dented crown fitting on the shaft of the pug mill.

The body descends by its own weight, but in order to increase the production, it is well to arrange the knives in spiral lines, tending by their movement to compress it towards the base.

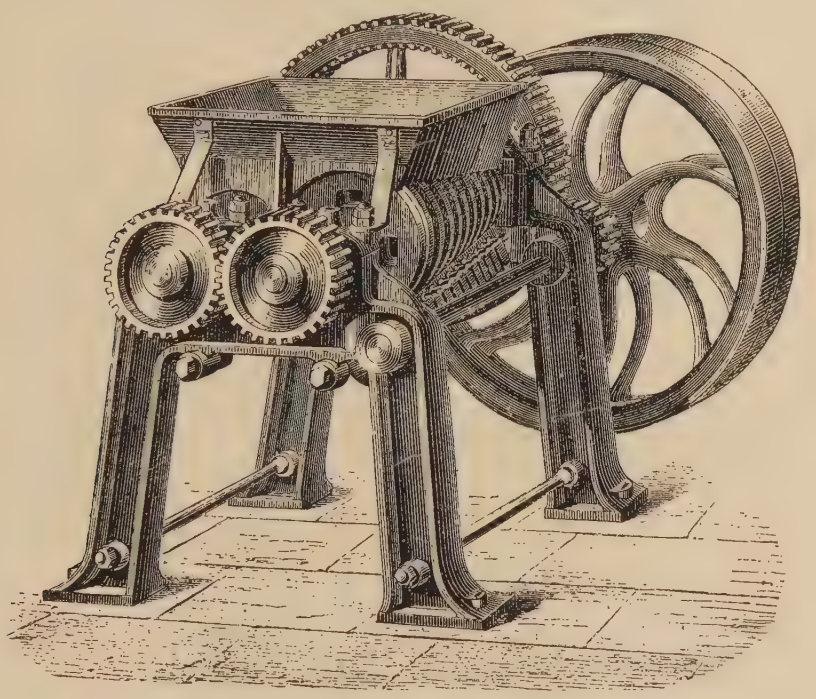

Fig. 29.—Fluted Roller Mill.

These spiral lines are generally provided with vertical knives helping to divide the mass. At the bottom of the pug mill is a double knife, of the form shown in Fig. 31, the object of which is to drive the pugged body towards the place of exit, whence it passes by jerks in the form of a fairly dense mass.

These pug mills are constructed with a diameter varying from 20 to 40 inches, and a height from 40 to 80 inches. The shaft making from 8 to 12 revolutions a minute, their output depends entirely on the degree of plasticity and the consistency of the

body; only rather vague indications can be given on this point. For open clays having a consistency corresponding to the moulding by hand, one horse can pug about $1\frac{1}{4}$ cubic yard per hour.

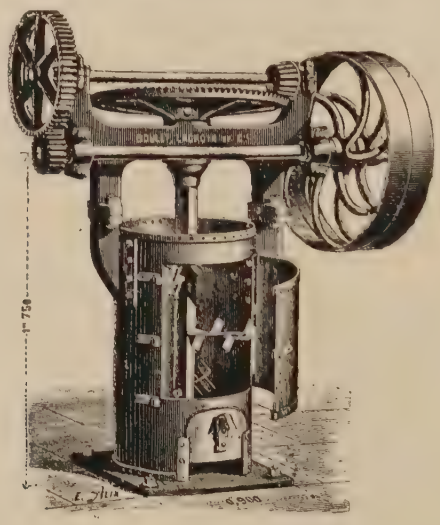

Fig. 30.—Vertical Pug.

For plastic clays the same result can only be obtained with two or three horses. With reference to pug mills worked by mechanical motive power, below is an approximate table of the

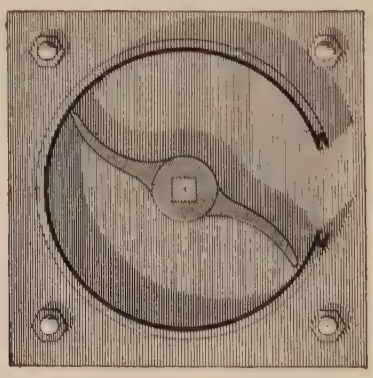

Fig. 31.—Plan showing bottom scraper.

conditions of their working, the smallest productions corresponding generally to the greatest expenditure of force.

| Diameter, inches. | Length, inches. | Production in $m^3$ per hour. | Horse-power. |
|---|---|---|---|
| 20 | 40 | 0·7 to 1·2 | 1 to $2\frac{1}{2}$ |
| $27\frac{1}{2}$ | 59 | 1·5 to 2·5 | 2 to 4 |
| $35\frac{1}{2}$ | 78 | 2·5 to 4 | 3 to 6 |

When it is desired to obtain bodies of greater consistency, it is preferable to use horizontal pug mills consisting of a horizontal

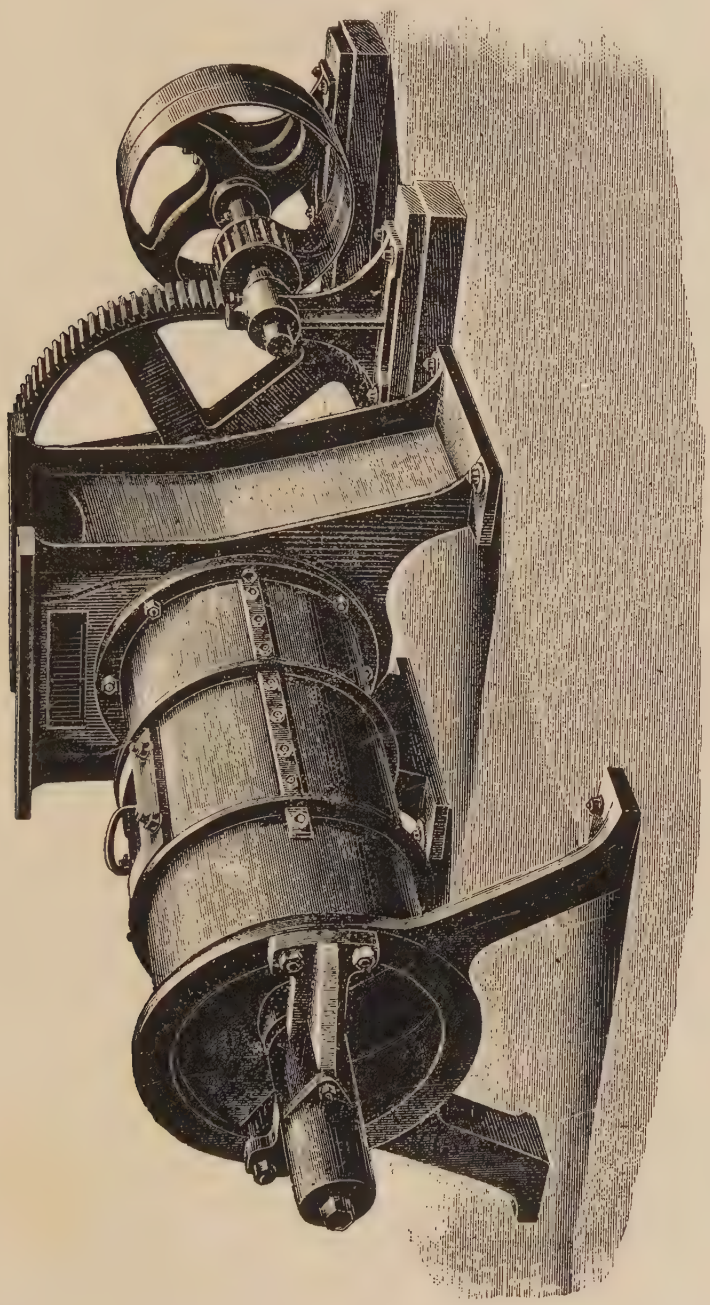

Fig. 32.—Horizontal Pug.

cylinder of sheet or cast iron, in the centre of which a shaft with knives is fixed.

This cylinder is closed at one end, and the shaft traverses the base by a fixed gearing. The body is introduced on this side and makes its exit by the other extremity, more or less opened, according to the degree of pugging to which it is desired to subject the body. Fig. 32 shows a pug mill of this kind.

The knives being of cast iron, or with shank of cast iron and adjusted blades of iron, have a helicoid shape, their width varying from $\frac{1}{8}$ to $\frac{1}{2}$. Usually the width of the knives goes on increasing from the bottom of the pug mill to the exit. Contrary to what takes place in vertical pug mills, the body, especially if it is rather plastic and consistent, has a tendency to turn with the pallets. In order to provide against this inconvenience, which would suppress all pugging, some "counter knives" are

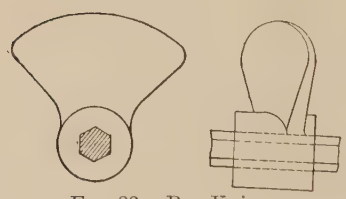

Fig. 33.—Pug Knives.

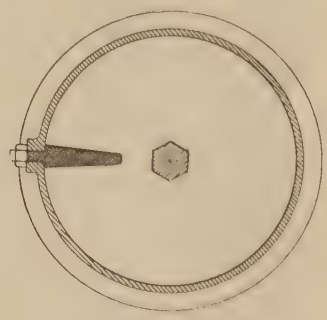

Fig. 34.—Horizontal Pug.

fixed in the cylinder (Fig. 34) intended to put a stop to the turning movement of the body.

These pug mills are constructed with diameters varying from 15·75 to 27·56 inches, length from 59·15 to 98·42 inches, the speed of rotation being from 10 to 15 revolutions a minute. The amount of work done can be approximately estimated as follows:—

| Diameter, inches. | Length, inches. | Production in $m^3$ per hour. | Horse-power. |
|---|---|---|---|
| 17·71 | 78·74 | 2 to 3 | 3 to 5 |
| 23·62 | 78·74 | 4 to 6 | 5 to 8 |

Horizontal pug mills can also be constructed with two rotary shafts bearing knives turning in opposite directions, according to the arrangement shown in Fig. 35. The pug, generally of sheet iron, is opened at the upper part. The body is fed at the side of the machine, and makes its exit by a lower aperture placed at the other extremity. The shafts, which, as in the preceding

horizontal pug mills, tend to recede, are upheld at the back by fixed gearing, and in front by rings.

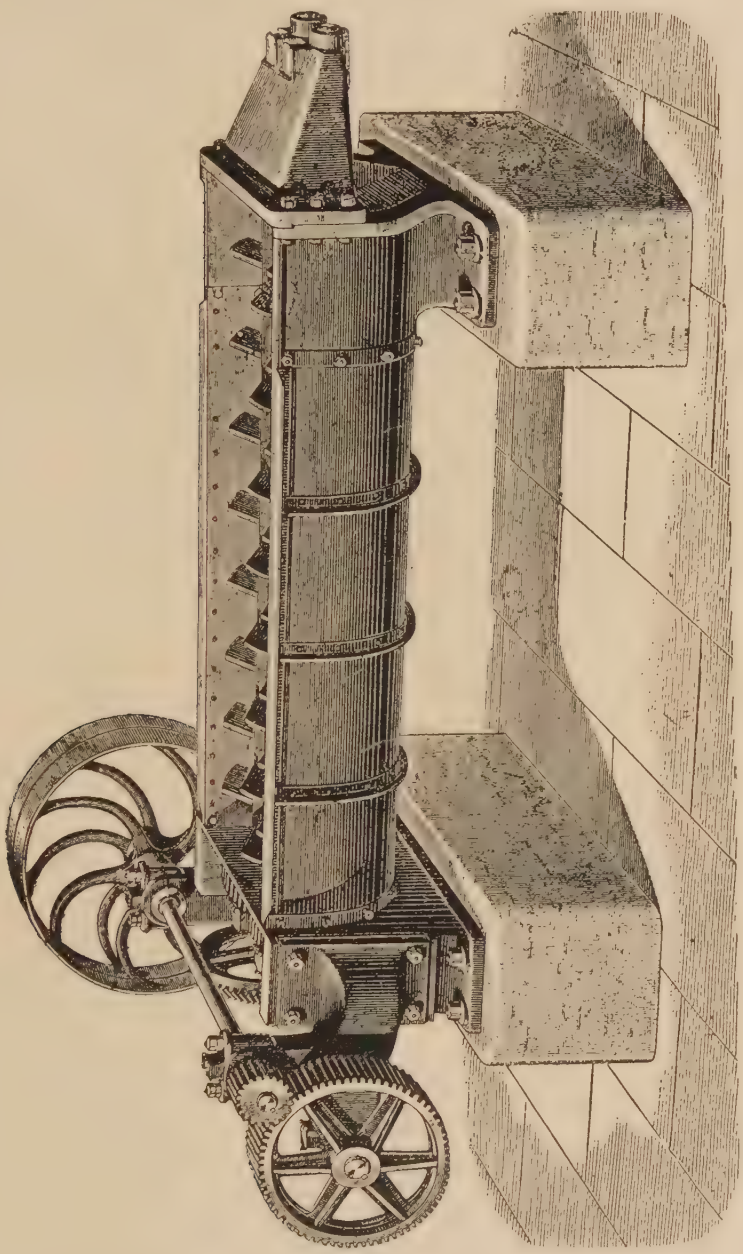

Fig. 35.—Horizontal Pug.

The knives have also a helicoid shape corresponding to $\frac{1}{8}$ or $\frac{1}{10}$ spire. They are set to work on footsteps of square or octagonal section in four directions. These pug mills are constructed with

a width of 21·50 to 39·37 inches, and a length of 118·11 to 138·79 inches. The speed of rotation is from 12 to 15 revolutions, and the production is from 70 to 140 cubic feet per hour, for an expenditure of force of from 3 to 5 horse-power. They are very good machines, having less wear and tear than horizontal pug mills with a shaft, but furnish a body of less density.

Whatever may be the system of pug-mill adopted, it is well, before using the body for formation, to let it remain in heaps covered over with damp cloths for at least twenty-four hours. It is only in the case of the manufacture of very ordinary wares, or when the actual formation is preceded by rough shaping, that the body can be used directly on its exit from the pug mill.

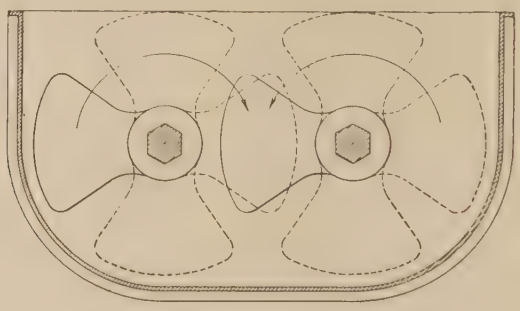

Fig. 36.—Double Horizontal Plug.

**88. Rolling and Pugging Combined.**—Rolling machines and pug mills, such as have just been described, can be placed on the ground by the side of each other, and the body made to pass from one apparatus into the other by means of endless bands. Another arrangement frequently used consists in placing the roller machines above the pug mills. The pug mill in Fig. 32 is arranged for this purpose. On the other hand, Fig. 37 represents the combination of a double pair of rollers with a vertical pug mill, and Fig. 38 with an horizontal pug mill. These machines are only indicated by way of example, for it is easy to find other arrangements.

**89. Preparation of Stiff Body.**—All the preceding is concerned chiefly with the manufacture in soft body, which is the most usual. In certain cases, however, it is desirable to have for-

mation with a stiffer body, which requires for its preparation some modifications in the preceding processes.

In this case the apportionment cannot be effected in pits, which would yield too soft a body; it is done in heaps, unless the raw materials have naturally the required humidity, which rather frequently happens.

Homogeneisation is effected by rolling and pugging as in the

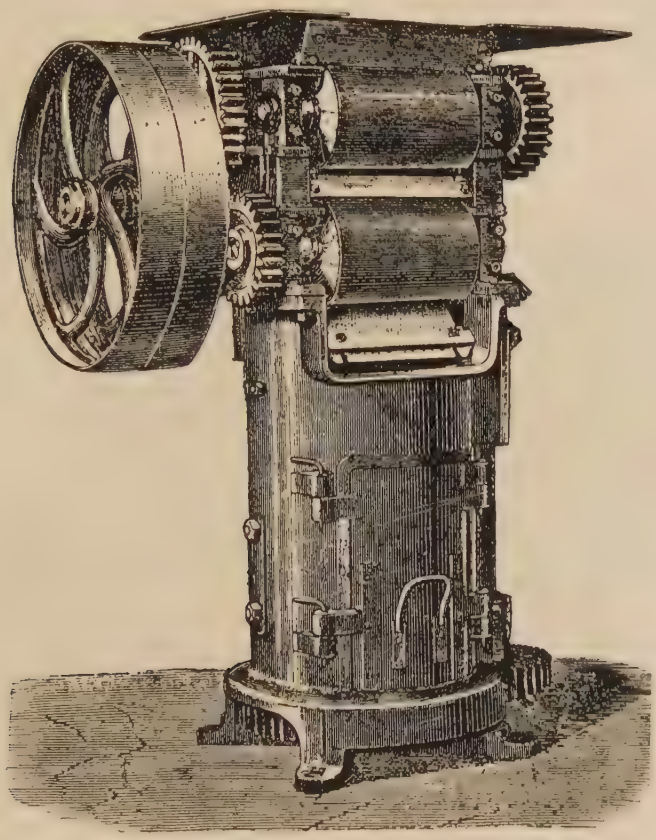

Fig. 37.—Vertical Roller Pug.

preparation of soft bodies, but the machines, always indispensable, which are used for this purpose should be more rigid, and require a more considerable motive force. Fig. 39 shows a double pair of rollers, the upper conical and fluted, the lower parallel and plain, constructed by MM. Boulet & Cie, specially for the rolling of stiff bodies.

The granulating rolling machine of M. Dumont (Fig. 40) also

gives results when it is desired to act on bodies containing clay pebbles. It supplements the always rather incomplete work of the pug mills when the latter have to mix too stiff a body. As is seen from the drawing, it consists of a first pair of upright and plain rollers and of a second pair of larger diameter, perforated with a large number of small holes through which the body is forced in order to fall into the interior of the rollers powerfully pressed one against the other.

Rolling is an indispensable operation in the preparation of stiff bodies, for the great stiffness of the body prevents the

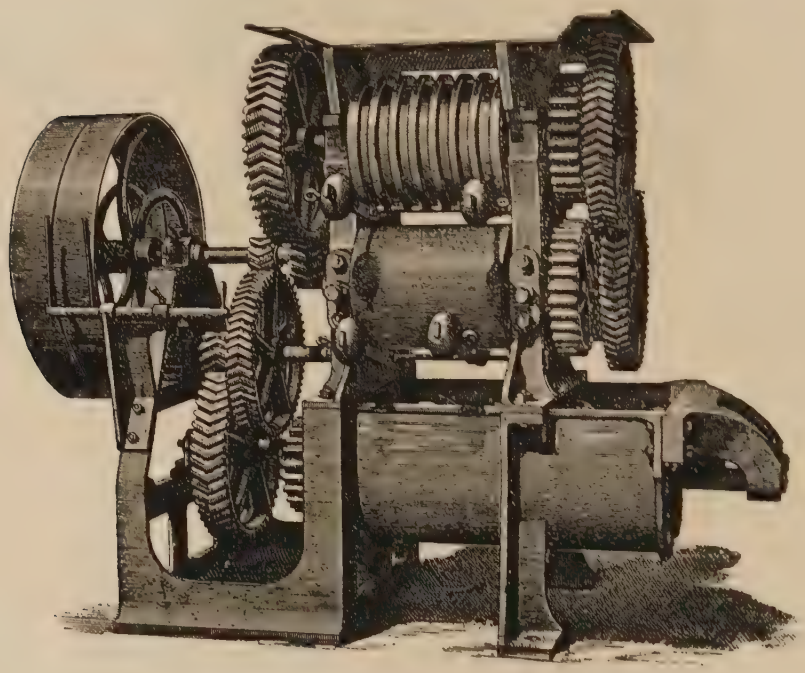

Fig. 38.—Combined Roller Mixer and Horizontal Pug.

pugging from being sufficiently efficacious. In this case only vertical pug mills are employed, of a small height—about 40 inches. Horizontal pug mills would necessitate too much power. Fig. 41 represents a pug mill of this kind, constructed by MM. Boulet & Cie, in which the driving of the shaft is made from the lower part. This machine, for a production of 2 to 3 cubic metres an hour, employs a force of from 5 to 6 horse-power.

In the preparation of stiff body it is not very desirable to allow the bodies to remain standing after their exit from the pug

mill before their formation. Moreover, the aim of all this manufacture is to work on the clays as they are found in their place of origin, and to obtain as speedily as possible marketable wares, which perforce requires a considerable development of mechanical machines. The frequent consequences of this will be seen in the chapter dealing with the manufacture of fired bodies for building purposes.

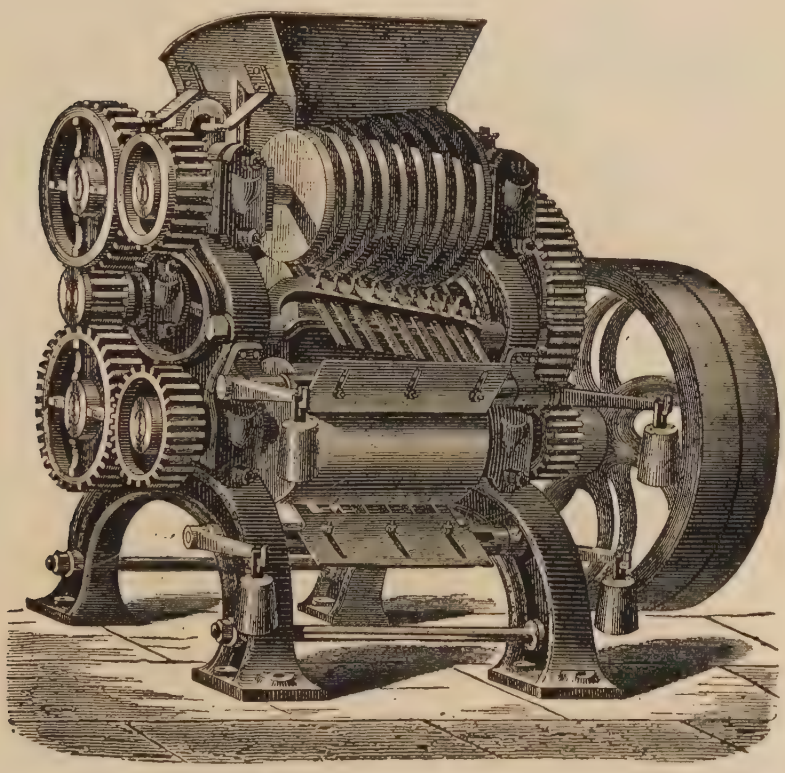

FIG. 39.—Double Roller Mill.

### (*b*) *Preparation by Dry Method.*

**90.** In preparation by dry method there are three distinct operations :—

Pulverisation of raw materials.

Apportionment.

Combination of water with the body.

Clays are first dried, then pulverised and sifted. Pulverisation is done by means of centrifugal grinders, ball grinders, rolling machines or vertical mills, similar to those described

above, but arranged so as to obtain a greater fineness. The pulverised material is afterwards sifted, the residue being brought again into the pulveriser.

The pulveriser shown in Fig. 42, constructed by M. Jannot, is used with advantage. The material ground by the mill is removed by an elevator on to a central conical sieve. The powder falls into a sort of sink pit, or can be drawn out by a second elevator. The core returns automatically under the mills.

These grinders have pans from 78·74 in. to 110·23 in. in

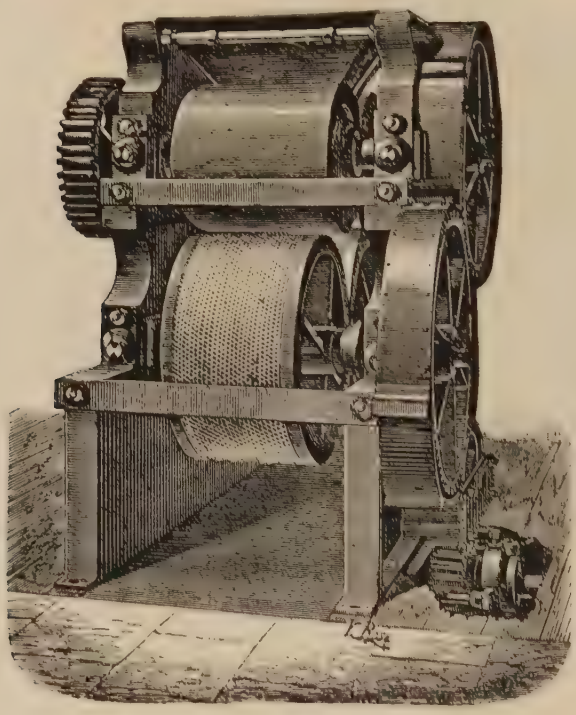

Fig. 40.—Roller Granulators.

diameter, with rolls of 59·05 in. to 70·86 in. The production, which essentially depends on the sieve, varies between 170 and 630 cubic feet a day for a force of from 4 to 5 horse-power.

The great drawback to all these machines is the production of a thick dust, which spreads into the shops and is very injurious to the health of the workers. There should be no hesitation, therefore, to use arrangements for hermetically closing the pulverisers and strongly ventilating the premises in which they are employed.

Antiplastic raw materials, which enter into the composition of bodies, are also, if there is an opportunity, pulverised and sifted by using stamping machines, centrifugal grinders, pounding or chopping machines, or the pulverising mill previously described.

The various raw materials being thus pulverised, and each

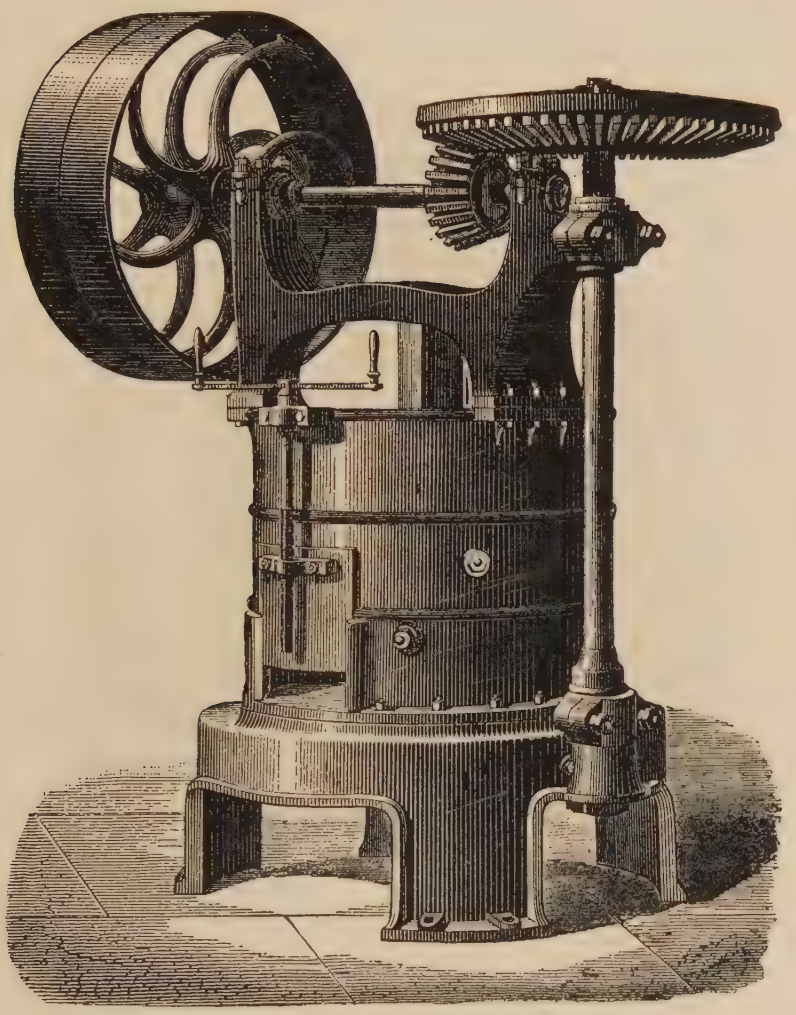

Fig. 41.—Vertical Pug.

having a suitable coarseness of grain, the apportionment is proceeded with. The latter is done by volume, generally a more exact process in ceramics than apportionment by weight, because of the variations in the weight of water contained in the clay, which, within the limits in which they are produced, have no influence

on the volume. Each raw material is measured in cases of determined capacity, then a preliminary mixture is generally made by hand on a slab. For this purpose it is seldom that a special machine is used. However, for a large production this system is preferable, and vertical or horizontal pug mills are used, or mixers with a centrifugal force, the construction of which is very simple and needs no special notice. At other times there

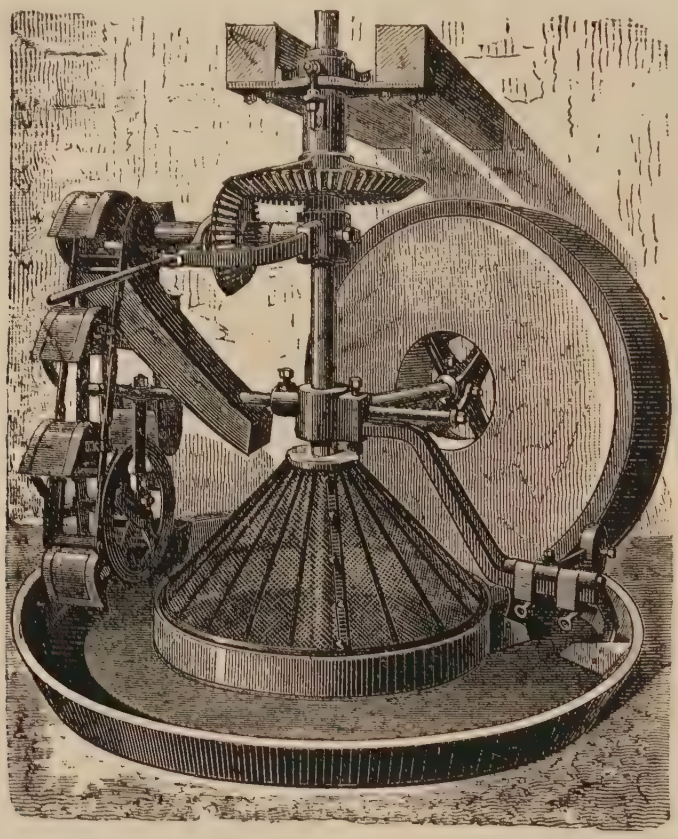

Fig. 42.—Pulverizer.

is no preliminary mixing and the materials are turned directly into a wet mixer.

The method which has just been described is employed whenever the different raw materials need not have the same coarseness of grain, or when sands or other substances having no need of being pulverised are used. If, on the contrary, all the materials have to be pulvérised uniformly, it is desirable to

grind them roughly, to apportion them in that condition, and to turn them into a pulveriser, which effects the mixture and pulverisation at the same time. Grinders with centrifugal force, ball pulverisers, or vertical mills are especially suitable for this purpose.

The moistening of the body can, for small productions, take place on the floor which has served to effect the mixture. After having added the necessary amount of water, the body is kneaded, then left standing for one or two days in order to be worked again. This primitive process has nearly everywhere given place to pugging. All the pug mills described above can be used for this purpose. It suffices to fix at the place of entry a pipe for the supply of the water, the flow of which is regulated by a tap. The pug mill with shafts is in this case a very good implement; it enables the water tap to be replaced by a pipe parallel to the shafts, pierced with a fairly large number of orifices, by means of which the water can be more uniformly agitated. Sometimes also a circular trough is made use of, in which the knives turn which take the raw materials and the water turned to the circumference, grind them and bring them towards the centre, where the prepared body falls by an aperture into the bottom of the trough.

Sometimes, for moistening purposes, warm water, and even vapour is used. It is then necessary to proceed at once with the formation, because the body dries rapidly. In all other cases it is preferable to allow the body which has been pugged to remain for several days, covering it with damp cloths to prevent it from drying superficially. This rest allows the grains of clay to become more completely combined with the water than they could have done during their rather short passage in the pug mill. The result is increase in plasticity of the body, which often facilitates much of the work of formation.

### (c) *Preparation by Liquid Method.*

**91. Methods of Preparation by Liquid Process.** — The preparation of bodies by means of liquid is done by two methods, which are distinguished by the physical condition of the materials at the time of the apportionment.

The first method comprises four operations:—

The apportionment of the raw materials in the dry state.

Blunging and mixing in water.

Sifting.

Hardening.

The second method also consists of four operations:—

Blunging of raw materials in water.

Apportionment and mixing in liquid state.

Sifting.

Stiffening.

The two last operations of sifting and stiffening of the body are performed in the same manner for both methods.

It is often necessary to add to these a fifth operation, the pugging and kneading of the body.

The dry apportionment of the first method is made without difficulties by volume, as has been noted in the preparation by dry means. A greater precision, however, must here be exercised, for bodies of fine faience and porcelain which are subjected to this process cannot, with impunity, allow of considerable divergence in their composition; on the other hand, the apportionment in a liquid state will need more detailed explanation. The study of preparation by liquid method will be dealt with in the following articles:—

Blunging of raw materials.

Apportionment and mixing in liquid state.

Sifting.

Stiffening.

Pugging and kneading.

**92. Blunging of Raw Materials.** Blunging of the clay is done in blungers similar to those used for levigation. As only those clays are used which are naturally pure, or which have been washed, there is no fear of the inconvenience resulting from the pressure of stones or coarse sand. The blunger shown in Fig. 21 is that most generally used. The blunger shown in Fig. 23 is also employed. The blunging is not done in a continuous manner, but fixed quantities of clay and water are introduced, then when the mixture is homogeneous it is poured into a basin.

If the clay has been washed near the place where the prepara-

tion of the body has been made, a fresh blunging is avoided by taking the clay from the decanting "arks". For this purpose arks of small dimensions are used which are filled at one time, then they are allowed to remain while the superfluous water is removed, until the consistency of the body is such that the antiplastic materials which are to be mixed with it can no longer be precipitated.

The body is then vigorously agitated with a rake consisting of a plank of at least 40 inches long, 12 inches wide, pierced with holes, and fixed at its centre to a long handle. This plank is made heavy by iron braces, or, better still, by lead, so as to compel it naturally to descend to the bottom of the ark. The object of this operation is to render the clay deposited homogeneous, by mixing the fine parts of the surface with the coarse parts, which are the first to be precipitated. For large productions this agitation can be done mechanically by using circular decanting arks, and providing them with agitators similar to those of the blunger (Fig. 21). The body having thus been rendered suitably homogeneous it is poured into an ark.

The blunging of antiplastic materials, quartz, felspar, etc., must be preceded by pulverisation, or at least by grinding. These materials are then placed with a suitable quantity of water into special blungers. For a long time horizontal roller mills, similar to those used for the grinding of corn, have been employed for this purpose. The grindstones, from 40 in. to 60 in. in diameter, are arranged in belfry fashion with four pairs of grindstones.

Again, these grindstones have often been replaced by blungers, designated under the name of grinders or levigating mills. Fig. 43 represents an apparatus of this kind. In a circular vat, the bottom of which is paved with hard stones, moves a vertical shaft provided with four horizontal arms, which impart their motion to blocks of stone.

An iron ring prevents these blocks from rubbing against the walls of the vat. The chief advantage of grinding mills is to avoid repairing of the mills. They are constructed with vats from 4 ft. to 6 ft. in diameter.

The Alsing Cylinder seems destined in its turn to replace grinding mills. It consists (Fig. 44) of an iron or steel drum, furnished inside with a coating of ceramic stoneware. This stoneware is

compressed in formation by means of hydraulic presses, and particles of silex are incorporated with it to prevent its becoming polished by usage. The working is done by introducing into the cylinder a

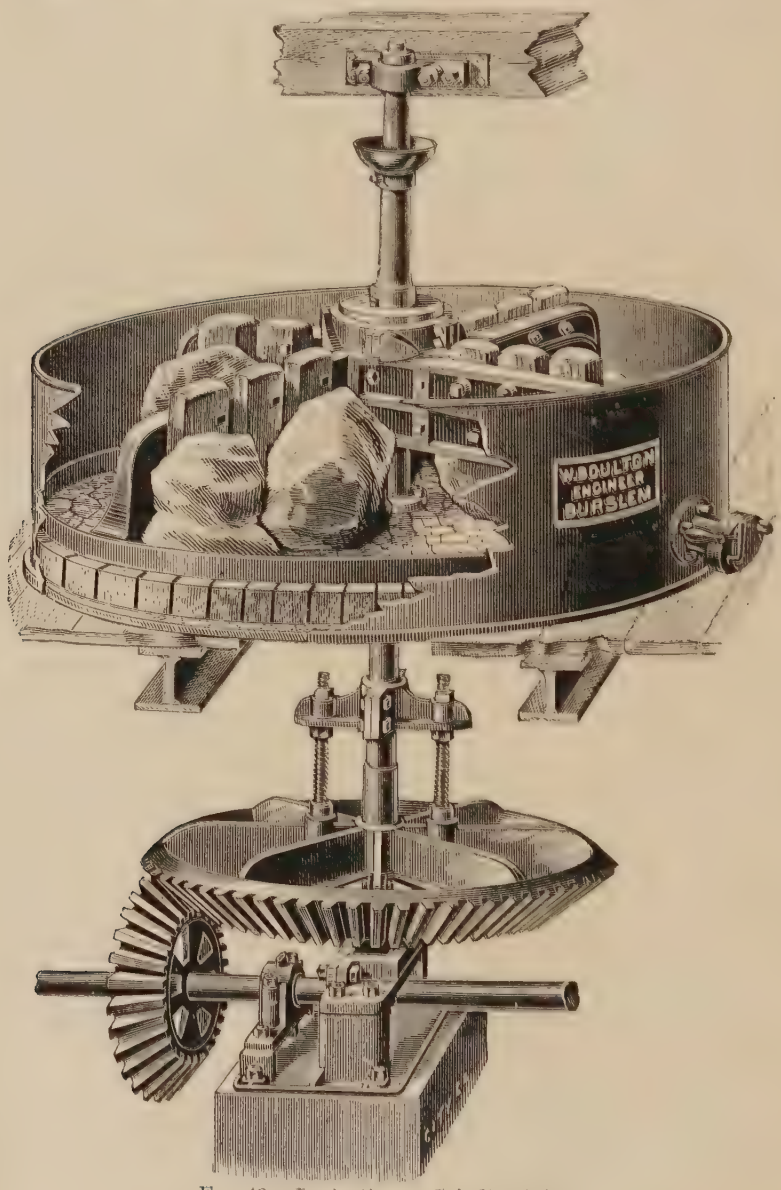


FIG. 43.—Levigating or Grinding Mill.

determined quantity of water and of antiplastic materials, and by causing the apparatus to work until the pulverisation and the blunging are complete. The door closing the cylinder is then

replaced by a grill, which allows the blunged substance to be poured into a basin, while the pebbles are kept back.

When the apportionment is made on dry raw materials, and when the clays and antiplastic materials are blunged simultane-

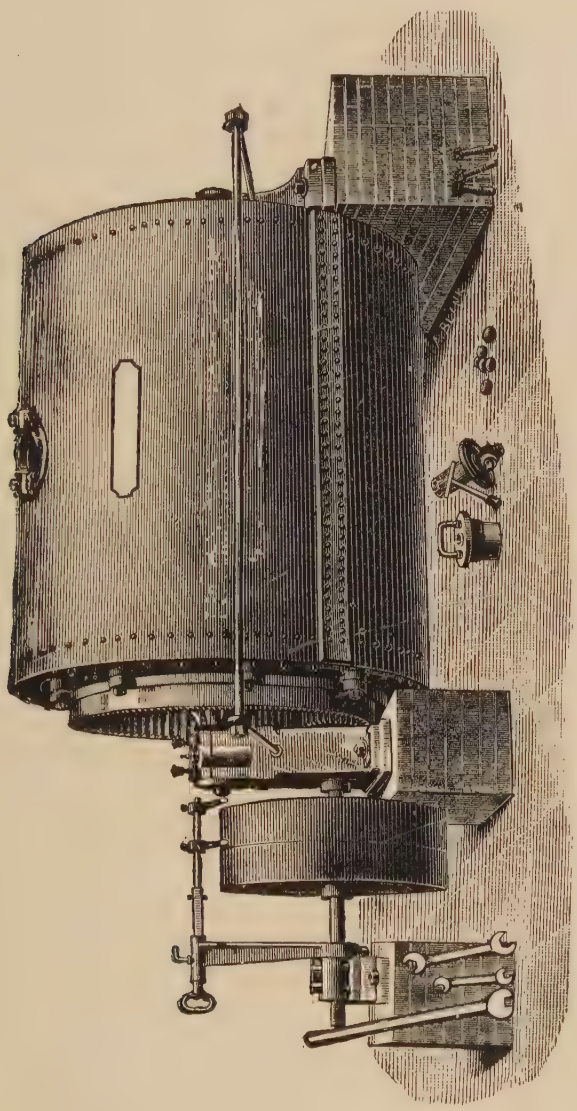

Fig. 44.—Alsing Cylinder.

ously, the same blungers are used for this purpose as for antiplastic materials only, that is to say, horizontal mills, grinding mills, or Alsing Cylinders.

The latter are constructed for loads from 335 lb. to 3,350 lb. of

ground silex; the amount of force employed varies from two to twelve horse-power.

**93. Apportionment and Mixing in Liquid State.** In order to mix together two or several substances blunged in water, it is essential that the liquid bodies should have approximately the same consistency, so that they may have no tendency to separate from each other. It is also necessary to keep them in a continual state of agitation, or at least to stir them frequently in order to avoid their settling. These two rules must be observed scrupulously, if it is desired to obtain an exact apportionment.

In order to know in what proportions it is suitable to mix several liquid bodies, it is necessary to know the weight of dry materials which they contain for a given consistency. This weight is easily obtained by drying at 120° C. a given volume of body, *e.g.*, 1 pint, and by weighing the dry residue thus obtained. Then a simple calculation of proportions enables one to determine in what ratio, by volume, the bodies should be mixed to obtain the composition by weight fixed *a priori*.

In order not to be obliged to constantly repeat this determination, which for industrial purposes would be somewhat inconvenient, it is arranged to constantly manufacture bodies having the same consistency adopted once for all. The measure of this consistency can be made by different means. Hydrometers can be employed, the use of which, however, is not to be recommended because of their want of exactness. It is preferable to measure the weight of a given volume of body. For this purpose a vessel of known capacity, say 1 pint, is made use of. After being filled it is placed on a pair of scales, where it is balanced by an invariable weight corresponding to the weight of the vessel, in addition to the weight of the body of the consistency adopted. If the vessel is heavier, it is because the body is too thick, and a little water is added to it; if the vessel is too light, there is too much water. The body is then allowed to settle for a short time in order to remove a certain quantity of water by pouring off, or even some body of greater consistency is added, which is contained in a basin prepared for this purpose. This operation is repeated until the body has the desired consistency. With a little practice, the variations are very slight and are corrected the first time without uncertainty.

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The different bodies, having been thus subjected to fixed circumstances, a vessel is filled with each of them up to a given level, corresponding to the volume calculated, as has been previously stated, and these different vessels are emptied into a receptacle where the mixture is made.

A single receptacle can also be employed which is provided with index marks, which correspond to the apportionment. The first body is caused to flow into it until the first mark is reached, then the second until the second mark is reached, and so on. In any case the mixture is easily done by a manual mixing.

**94. Sifting.**—The object of sifting is to separate from the body the grains which were able to escape in the blunging and pulverising. This operation presents certain difficulties, by reason of the consistency of the body, and because the grains of sand, surrounded by clay,

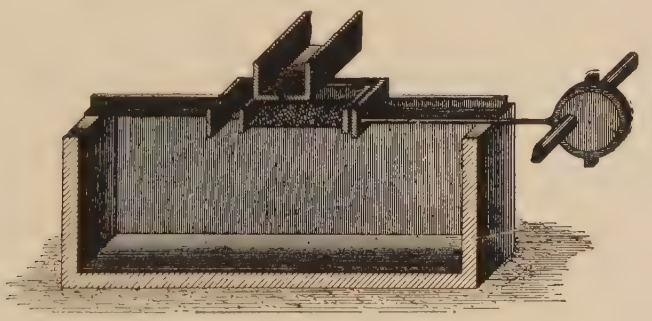


Fig. 45.—Lawn or Sieve for Slip.

have a tendency to remain in the holes of the sieves. In order to prevent the latter from being too rapidly obstructed, they might be shaken and struck constantly. For a small quantity this operation is done by hand, but in factories where a motor force is adopted the arrangement shown in Fig. 45 is generally made use of. Above the vessel intended to receive the filtered body two slides are placed, between which is moved a frame to which is communicated an alternative motion by means of an eccentric wheel. Inside this frame is placed the sieve resting on two longitudinal slides fixed to the frame. The sieve is slightly less wide than the frame, so as to slide easily, but it is perceptibly shorter. When the frame is impelled by the eccentric wheel, the sieve is drawn by this movement; but, when the eccentric wheel has arrived at the end of its course, the sieve, in consequence of its impetus, continues to advance

and strikes the opposite edge of the frame. Therefore to each oscillation of the frame are a corresponding displacement of and blow to the sieve. The body to be filtered is brought above the sieve by a trough at the bottom of which are pierced some holes. From time to time the arrival of the body is stopped, the sieve is removed, is overturned, being struck to cause the residue to fall.

The sieves have meshes of silk, or, better, of wire. Generally one sifting is not sufficient, the body is made to pass through two or three sieves, each finer than the other. For large quantities several sieves are arranged by the side of each other in the same frame.

Sometimes these sieves are replaced by revolving bolters similar to those used in mills. An horizontal framework of six or eight sides is covered with a cloth which allows the body to pass, this being introduced at one of the extremities, while the parts which have not been able to penetrate go out by the other. On the beam of the framework a pulley is mounted which communicates to it a revolving movement.

95. **Stiffening.**—The filtered body has not enough consistency to make it lend itself to formation, unless the latter is done by slip casting (Chapter IV.); a certain quantity of water must then be removed from it. This operation is called stiffening.

It has been seen when dealing with levigation that this stiffening can be obtained by evaporation in the air in decanting tanks. This process, applicable in grinding for ordinary clays when the question of economy is of the greatest moment, is not practicable for the preparation of bodies by liquid means. In this case a supplementary expense, always slight in comparison with the value of the ware, has less importance, and, moreover, it is much more expedient to work rapidly and not to occupy a considerable ground space.

The stiffening of bodies by artificial means has for long been the object of research among ceramists. Many processes were used up to the time when the improvements of the filter presses invented by Needham gave a satisfactory solution of the problem. Few words, therefore, need be said about the other processes, which have been more or less abandoned.

It is natural to seek to replace solar heat by artificial

heating. This was done by arranging heated floors by means of special fire grates, or by waste heat. These floors are made with plates of cast iron, covering a series of stonework channels placed between the fire and chimney, and arranged so as to present a large surface for utilising the heat in the best possible manner. The layer of body is from 12 in. to 14 in. It must be stirred constantly during the operation in order to prevent the lower parts drying completely. The body, when stiffened to the appointed degree, must be collected in "balls" and placed in cellars for several weeks in order that the humidity may be distributed uniformly throughout the entire mass.

For stiffening bodies the method of absorption by porous terra cotta or plaster vessels has also been made use of. This process is still employed in small potteries. Terra cotta vessels are rendered as porous as possible by adding to their body sawdust, or other organic substances. After being filled with the body they are placed on shelves exposed to the wind in order to hasten evaporation. Plaster vessels are very thick, so that they are able to absorb a larger quantity. When they are saturated they are placed in drying stoves to be dried.

Talabot proposed the use of filters formed of flat circular basins, the bottom of which, in the form of a flattened funnel, is covered with a cloth, then with a layer of grit, below which is a space. The water impelled by the atmospheric pressure passes through the filter, leaving the hardened body on the cloth. Then also the use of strainers has been favoured, similar to those used in the manufacture of sugar, or in bleaching houses.

As has been said above, we now use exclusively "filter presses," machines in which the liquid body, being compressed by a pump, is compelled to become filtered through a strong cloth, which retains it and lets the water pass through.

The first presses used had the arrangement shown in Figs. 46 and 47. A series of wooden frames (from 6 to 30) are pressed one against the other by means of iron bars. Into the spaces left between them cloths are packed which, their ends being folded, present the form of bags. At the upper part a pipe brings the liquid body under pressure into the interior of each bag. The water passes through the cloth, into the side

grooves of the frames, and escapes by a series of lower apertures. When the bags are filled with stiff body, the bars are loosened, the frames are removed, being laid hold of by notches in the sides, and cakes of body are removed from the cloths.

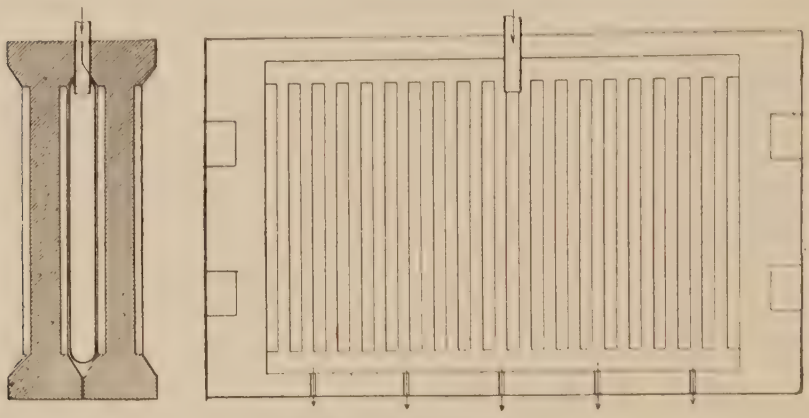


Fig. 46.—Filter Press.

Now the mode of construction preferred is that represented in Fig. 48, in which the cloths are pressed between a solid disc and a frame, the thickness of which varies according to the nature of the body. The latter is introduced through a central

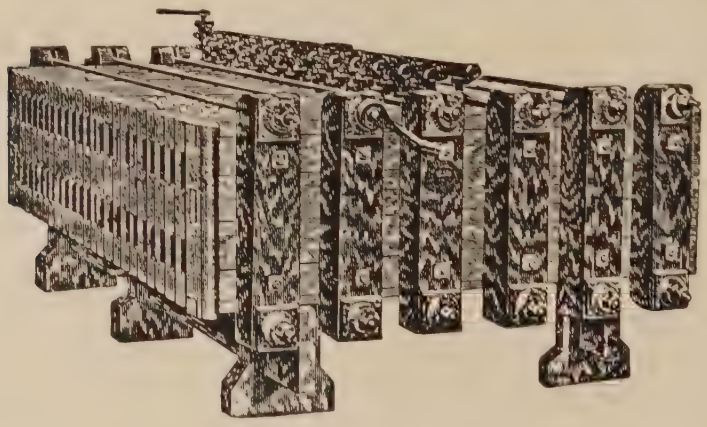


Fig. 47.—Filter Press.

aperture, the cloth pierced in its centre being fixed against the disc by means of a filleted tube. The water penetrates the cloth, flows along the flutings of the discs, and goes out by a lower tap.

Fig. 49 shows a similar arrangement of a filter press constructed by M. Leclaire. The discs and frames rest on two strong iron bars, and are pressed between a fixed end and a movable end by means of screw nuts which are screwed on

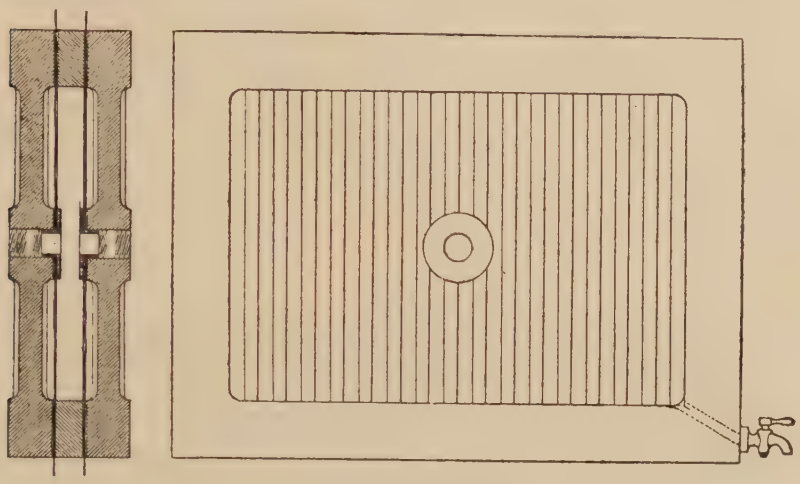


Fig. 48.—Filter Press.

the bars. The press being tightened and ready to work, the body is introduced by a central aperture arranged in the fixed

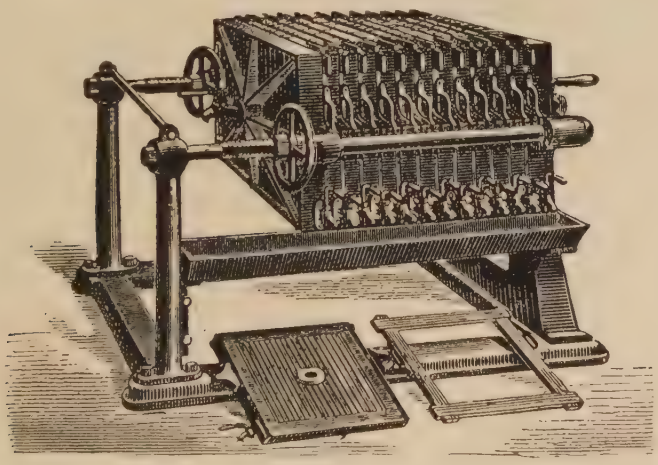


Fig. 49.—Filter Press.

end; it is distributed in the space left between the cloths of the first frame, then successively in the others until the whole press is filled. The introduction of the body is still continued until the latter reaches five to six atmospheres. The water which

flows by the taps is collected into a side trough. When the flowing ceases the working of the pump is stopped, the screws are loosened, the frames are removed, the cakes of stiff body fall of themselves, and can be collected in small trucks placed underneath the press.

Fig. 50 shows a press of the same kind, but more powerful. In this case the discs and frames, instead of sliding on the bars, are suspended in the frame by rollers, and the pressing is done through the medium of toothed wheels. This type of filter press is generally used in France and Germany; in England, on the contrary, the press represented in Fig. 51 is

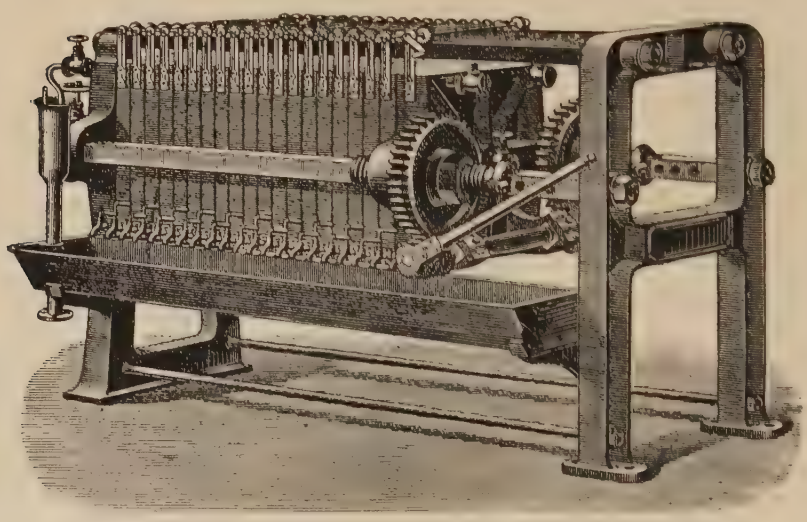


Fig. 50.—Filter Press.

commonly used, having circular discs sliding on the frame. The pressing is done by means of a screw which has its point of support in the structure.

Some machine builders allow the body to penetrate through one or several apertures, arranged in the periphery of the frames, and of the discs; but this arrangement is not to be recommended because the body is distributed less uniformly. For very large presses the tightening screw can be replaced by the action of an hydraulic piston. Here are some reports on the different sizes of filter presses:—

| Dimensions of Frames. | No. of Frames. | Volume of Body Hardened. |
|---|---|---|
| Inches. | | Pints. |
| 23·62 × 23·62 | 6 to 24 | 61·6 to 255 |
| 31·50 × 31·50 | 18 to 30 | 308 to 572 |
| 39·37 × 39·37 | 24 to 40 | 792 to 1,320 |

The volumes of body stiffened is calculated by allowing a thickness of cakes of 1·18 in. For open kaolin bodies this can reach 1·57 in.; on the other hand, for clayey bodies it must be

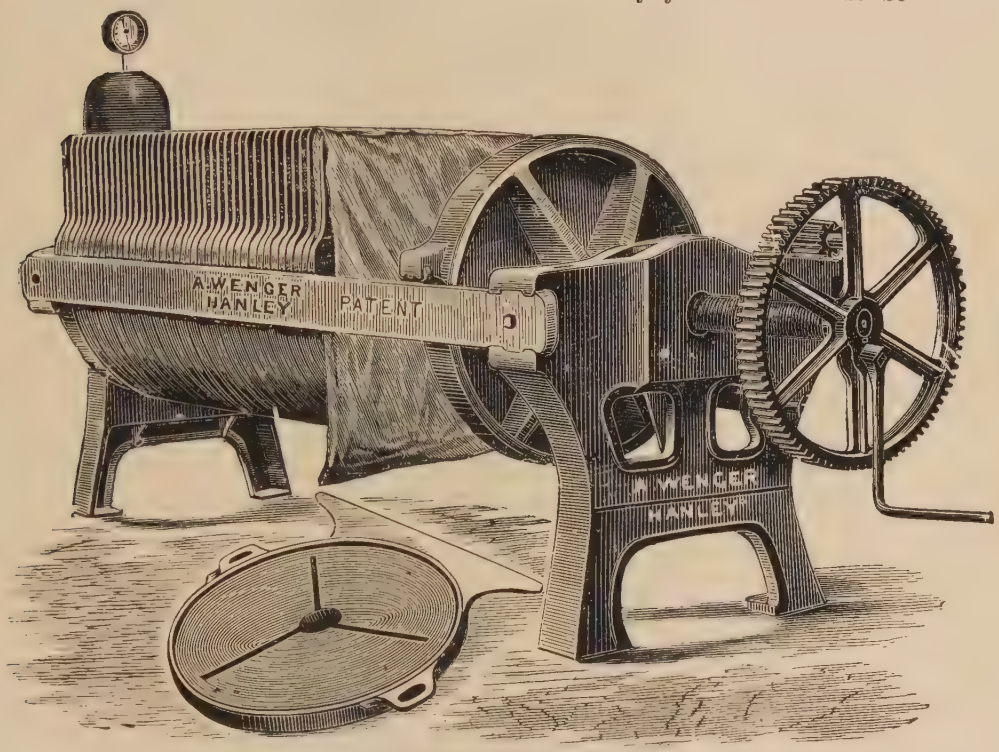



Fig. 51.—Filter Press.

reduced to ·787 in. or even ·59 in., which is easily done by modifying the thickness of the frames. It must be observed that the more plastic the body the more difficult its stiffening becomes by means of filter presses, becoming almost impossible for a body of pure plastic clay. The duration of an operation varies from two to four hours. After several operations the cloths must be washed, which can be done by letting a current of water circulate in the press, the ordinary taps for the exit of the water being closed. It is also well to provide against

rotting by washing them from time to time with very diluted phenic acid.

The body is compressed into the press by means of pumps called "membrane pumps". The latter consist of a "plunging piston" of simple working (Fig. 52), which does not act directly on the body, but through the medium of an india-

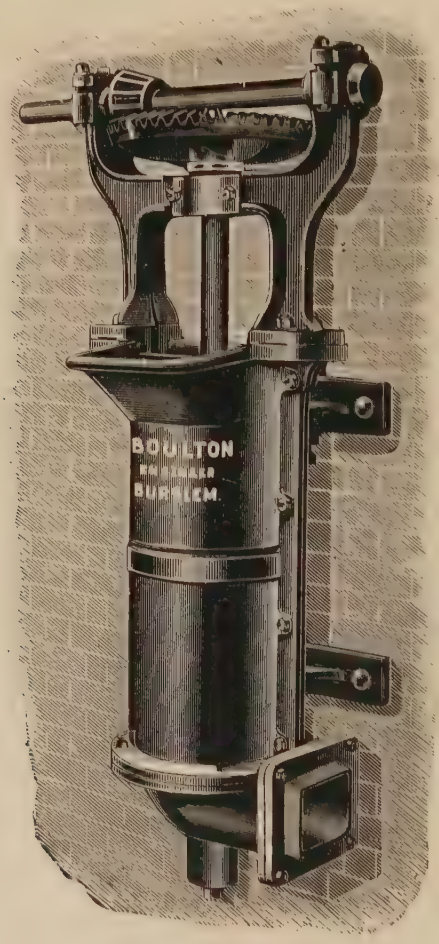



Fig. 52.—Vertical Pug.

rubber membrane, rising and falling at each piston blow, in a lenticular space. The body is drawn in by a ball valve when the membrane rises, and compressed by another similar valve when it comes down again. A side opening in the pump allows the desired quantity of water to be introduced, which serves as an intermediary between the piston and the mem-

brane. This aperture is provided with a safety valve. Some machine builders make the latter automatic by permitting it to act on the motive mechanism, when the greatest pressure is attained.

For small productions these membrane pumps are moved by manual force, for medium productions they are worked by an eccentric wheel mounted on the transmission; finally, when it is desired to work several filter presses at the same time, it is preferable to make use of a single pump, arranged horizontally, and set in motion by a pulley. In ceramics there would rarely be any advantage gained by using a special machine for this purpose.

The stiff clay coming out from the filter presses has generally a semi-stiff consistency. In works which manufacture and sell body exclusively, the cakes are often dried by arranging them on shelves, well aerated or heated by means of hot air stoves.

**96. Pugging and Wedging or Slapping.**—Whether the body has been so dried and water must be added, or whether it is used directly it comes from the filter press, it must be pugged so that it may have a uniform consistency and the homogeneity restored to it, which has in part been lost in the filters. For this purpose the different pug mills, previously described, can be used, but the vertical pug mill shown in Fig. 52 is frequently made use of. In this the body is rather powerfully compressed in consequence of the horizontal position of the orifice of exit.[1]

Notwithstanding this compression in the pug mill, the bodies always contain a certain quantity of air-bubbles, which occasion inconveniences in the formation, especially for fine and thin wares. In order to free the bodies from these, recourse must be made to a final operation designated under the name of "wedging" or "slapping". The latter is often done by hand, but for large productions this long and laborious work is replaced by machines.

They consist of a revolving pan, in which move fluted cylinders. In other arrangements the pan is fixed and the cylinders movable. These pans have a diameter of 3 ft. to 6½ ft., that of the cylinder being from 16 in. to 24 in.

[1] The mill shown in the illustration is intended to obviate the necessity for wedging.—W. P. R.

# CHAPTER IV.

## FORMATION.

SUMMARY.—Processes of Formation. (*a*) *Throwing:* Potter's Wheels—Mechanical Wheels—Processes of Throwing—Turning. (*b*) *Expression:* Dies—Propellers—Cutting Apparatus. (*c*) *Moulding by Hand:* Moulding with Wooden Moulds—Plaster Moulds—Moulding with Plaster Moulds. (*d*) *Moulding on the Jolley:* Jolleys, Moulds and Profiles—Processes of Moulding on the Jolley. (*e*) *Moulding by Compression:* Moulds—Presses. (*f*) *Moulding by Slip Casting.* (*g*) *Finishing.* (*h*) *Slipping.*

**97. Processes of Formation.**—By the term "formation" is meant the whole of the operations to which plastic bodies are subjected in order to give them the shape of the articles to be manufactured. According to this shape, the formation is accomplished in one or several operations. Formation, properly so called, can be preceded by "wedging" and followed by "slapping," words which sufficiently designate the kind of operation to which they apply.

The method of formation which at first sight appears the simplest is that which is done exclusively by hand, with only the assistance of a few manual tools. This process, naturally, solely employed before the invention of mechanical machines, is now only used for the making of original models: a few words will be said about it when dealing with the decoration of pottery ware.

Formation for manufacturing purposes, that is to say, that which has for its object the reproduction of a larger or smaller number of similar articles, can be done by three processes—throwing, jollying and moulding.

Throwing is based on the use of the wheel. It can only therefore be used for the making of round objects. The body should have a semi-soft consistency, so that the article does not lose its shape under its own weight, but should be soft enough to lend itself easily to the pressure of the hand. Sometimes this making is done in a single operation; at other times it is first shaped, then, when the body is stiffened, a second forming is proceeded with, which is termed turning.

In jollying, the body is compressed and forced to become

stretched out by means of a profile, having the outline of the article to be made. This process is only applied to the manufacture of cylindrical or prismatic objects. The body used is usually semi-soft, but sometimes the jollying is done with a semi-stiff or stiff body.

Moulding is done in moulds, the spaces of which correspond to the solid parts of the articles to be made. The shape of the latter may be any which will naturally lend itself to removal from the mould.

*Moulding by Hand,* in which the body, having soft or semi-soft consistency, is placed by hand into the mould.

*Moulding by Jigger,* employed for round or oval articles, the semi-soft body receiving the desired form partly by moulding and partly by jiggering.

*Moulding by Press,* in which the body is compressed in the interior of the mould. This body can be, according to the pressure exercised, semi-soft, semi-stiff, stiff or dry.

*Moulding by Casting,* employed for liquid body, which is poured in a mould with absorbing sides, on which it is placed.

Making by hand, moulding or by jigger can be done in a single operation; at other times it is preceded by a shaping obtained by throwing, by jollying, or by moulding.

Making by press, when it is done in soft or stiff body, is always preceded by a shaping by one of the three processes. On the other hand, moulding by press in dry body and moulding by casting only require a single operation.

Whatever may be the process employed, the making is often followed by a finishing or "fettling," a term under which is designated a series of operations fairly diverse, destined to give to the object its definitive form. Of these operations those which are specially for ornamentation will be dealt with in the chapter devoted to the decoration of pottery ware.

Finally, this chapter will be brought to a close by the description of a special process consisting in covering the body made with a thin layer of another body, a process known by the name of "slipping".

### (*a*) *Throwing.*

**98. Potter's Wheel.**—The "wheels" used in ceramics are of two kinds: potter's wheels, which are put in motion by the thrower, or

by an apprentice, and mechanical wheels, which are worked by an engine.

The potter's wheel is not only the oldest machine employed in ceramics, but is one which renders most service for the making of round pieces. It consists (Fig. 53) of a vertical spindle, the lower end of which rests on a footstep, fixed in the ground, and which is secured at its upper part by a collar fastened to a table placed against the exterior wall of the workshop. This spindle is surmounted by a small stand called the wheel head, holding the

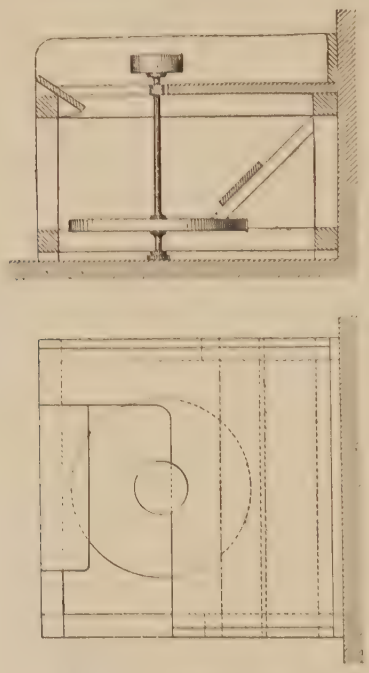


Fig. 53.—Potter's Wheel.

piece to be made, and carries towards the lower part a heavy solid fly wheel, which the workman sets in motion with his feet. The thrower is seated on an inclined small board, placed near to the level of the table, and can rest his feet, when the jigger has the desired speed, on another inclined board. The speed can at any moment be augmented or diminished, either by giving a fresh impetus, or, on the contrary, by allowing the foot to rub on the fly-wheel in order to check it. The preceding arrangement is employed in French and English potteries. In Germany a wheel of the same kind is also used, but the upper part of the wheel is

fixed by a piece of wood under the seat of the thrower, who is thus astraddle. Moreover, the fly-wheel is less large, but thicker, and the workman rests his feet by spreading out his legs on two pieces

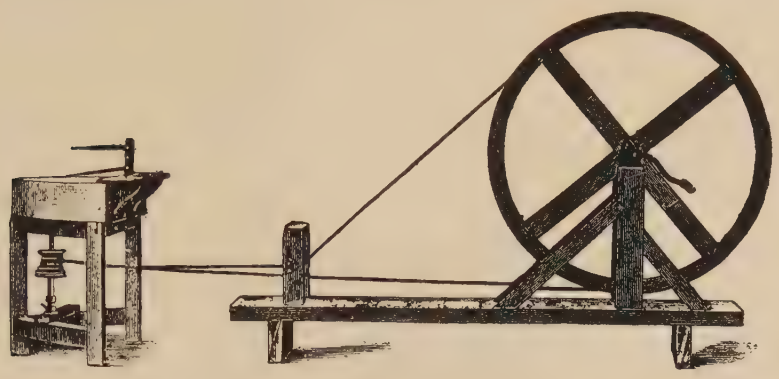


FIG. 54.—Potter's String Wheel.

of wood at the side. When pieces of fairly large dimensions have to be thrown, an apprentice transmits motion to the wheel by means of a handle. Figs. 54 and 55 represent arrangements of this kind. A certain amount of skill is necessary to enable the

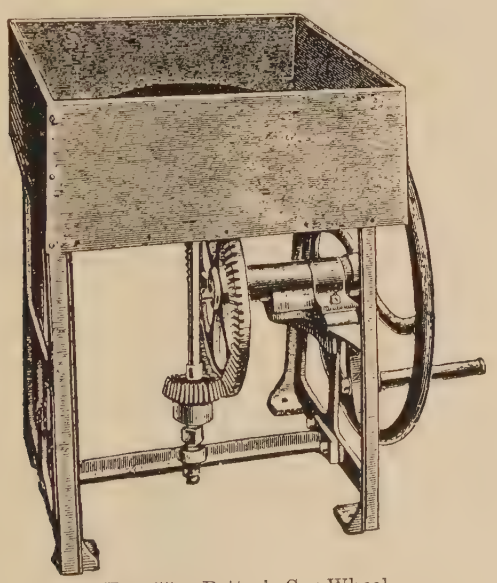


FIG. 55.—Potter's Cog Wheel.

apprentice to properly regulate the speed of the wheel to the requirements of the thrower.

99. **Mechanical Wheels.**—For large productions it is de-

sirable to replace the previous wheels by mechanical wheels, that is to say, by causing the motion by a transmission, the making being always done by hand.

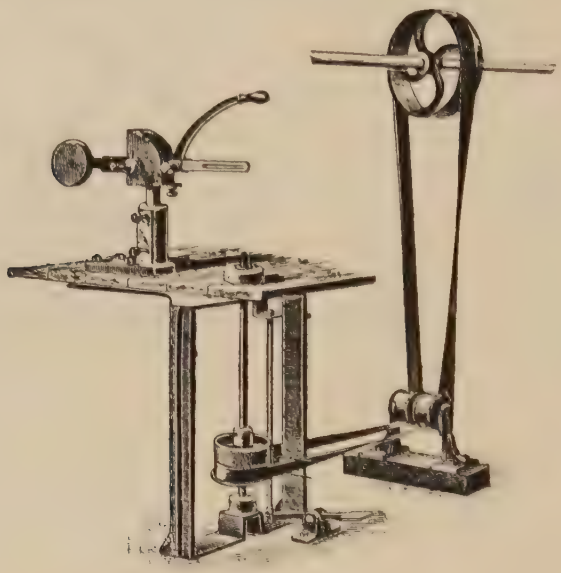


Fig. 56.—Jigger.

When small objects have to be made of shapes which are not complicated, and which do not therefore cause much variation in

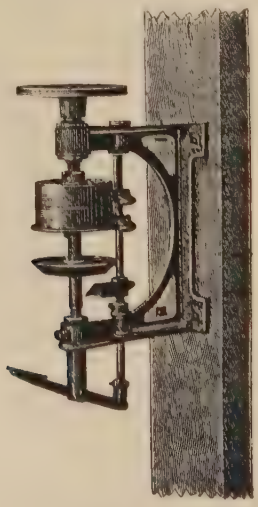


Fig. 57.—Potter's Machine Wheel.

the speed of the wheel, wheels of invariable speed may be used. In this case motion of horizontal transmission is communicated to

the vertical spindle of the wheel by means of a travelling roller, as represented in Fig. 56. The starting is done by means of a pedal placed near the thrower, so that he may only have to rest the end of his foot to set the wheel in motion, it being brought to a stand-still automatically when he ceases to touch the pedal.

Fig. 57 shows an inverse arrangement. In the latter the thrower, by leaning on the pedal, starts the mechanism and makes a check which, rubbing on a conical wheel, rapidly stops the rotation.

When on the same mechanical wheel it is desired to make articles requiring various rotatory speeds, it is possible to vary the speed of the transmission either by altering the diameter of the

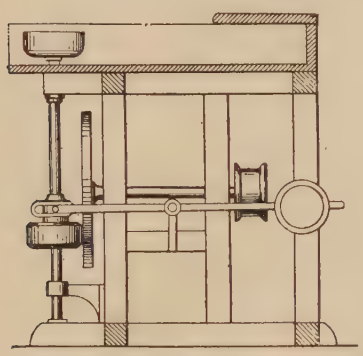


Fig. 58.—Machine Wheel.

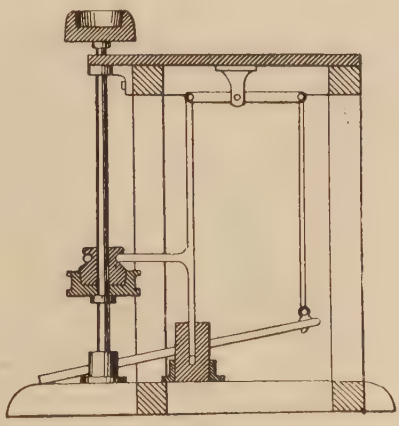


Fig. 59.—Machine Wheel.

pulleys, or by inserting an intermediary transmission caused by means of conical drums.

These arrangements are no longer sufficient when, in consequence of the dimensions of the body to be thrown, or of the difficulties which its making presents, it is necessary that the thrower should be able to modify the speed at any moment as he does on the potter's wheel. There are several solutions to this problem of mechanics, which has often excited the ingenuity of inventors. It can be solved by communicating motion to the spindle of the wheel by means of a pinion, whose point of contact with a motive disc can be displaced from the centre to the circumference of this disc, as shown in Fig. 58. A counterpoise tends to bring the pinion towards the centre, in which case the speed is made void, while

the thrower, by leaning more or less on a pedal, makes it descend while communicating to it speeds more or less great.

When the throwing requires little force, it is preferable to make use of the very simple arrangement shown in Fig. 59. The motive pulley is mounted on the spindle and carries at its upper part a conical space into which a piece can penetrate which is also conical, fitting on the spindle, but capable of being raised or lowered by means of a mechanism worked by a pedal. When the thrower does act on the latter the two cones are entirely fitted in and the wheel takes its maximum speed. If he leans lightly on the pedal

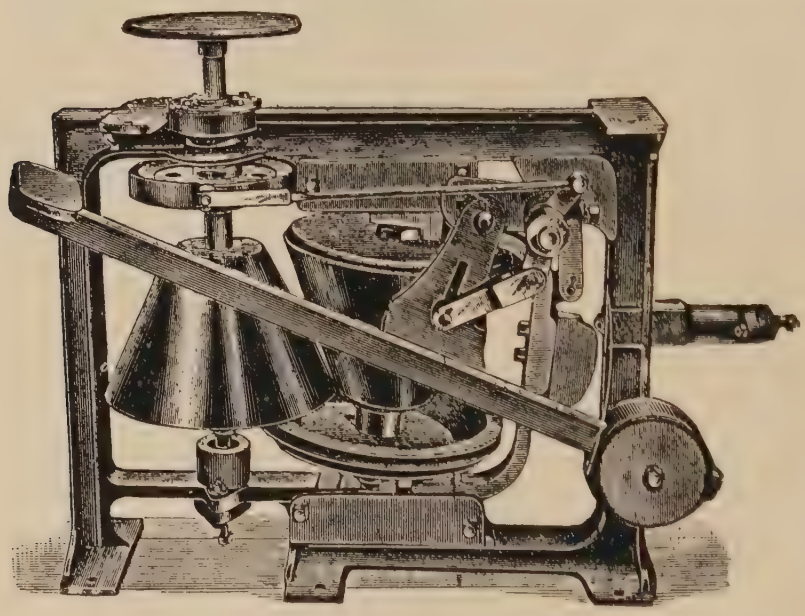


Fig. 60.—Potter's Cone Drum Wheel.

the contact is less perfect, it produces a certain sliding and the speed is slackened. If, finally, he presses more heavily, the contact ceases and the wheel stops.

Lastly, the cone drum wheel, constructed by Mr. Boulton (Fig. 60), solves the question in the most complete manner, but has the drawback of requiring a rather complicated mechanism. On the spindle of the wheel is a cone which can be set in motion by a second cone placed in a contrary position, having a slightly arched surface, and which can be displaced at the same time as a frame, the ends of which are caught in two slides, an upper

and a lower, fixed in the structure. This second cone has a continuous and rotatory movement caused by a thick rope passing on a pulley with fluted neck on the spindle. A pedal is fixed conjointly to the frame, and its counterpoise tends constantly to bring the mechanism into the position shown in the figure, in which the two cones are not in contact, the wheel being consequently immovable. If the thrower presses on the pedal, this movement, causing the frame to slightly turn, pushes it against an elastic spring contained in an horizontal cylinder fixed to the back of the structure. Under the influence of this spring the frame is impelled towards the front, and the small circumference of the motive cone enters into contact with the largest diameter of the cone fitted on the spindle of the wheel, to which it communicates the least speed of which the apparatus is capable. If the thrower continues to press on the pedal the oscillating movement of the frame continues, and the increasing diameters of the motive cone arrive successively in contact with the decreasing diameters of the cone placed on the spindle of the wheel, so that the speed goes on increasing until the upper ends of the cones are in contact. The thrower can thus, by pressing more or less on the pedal, and without great effort, make the speed vary at will. For wheels of large dimensions, a check mounted on the spindle of the wheel stops the movement when the pedal is left to itself.

Mechanical wheels are usually arranged beside each other so as to be able to be worked by the same transmission, placed preferably on the floor of the workshop. They can also be made to move by means of a continuous rope, which Mr. Boulton has proposed, as shown in Fig. 60.

**100. Processes of Throwing.**—In order to make a piece of any form, the thrower takes a quantity of body, proportionate to the size of the object to be made, and places it on the wheel head of the wheel (Fig. 61). He then sets the wheel in motion, and, after having placed his fingers in some water, he takes the mass and forces it to rise and fall several times, then with the thumb on one part and the other fingers on the other, he obliges it gradually to assume the desired form. He then smooths the surfaces by means of a sponge. This operation, which at first sight appears

very easy, requires, on the contrary, a great deal of practice to press the mass uniformly, and to prevent knuckle marks from forming, a defect which is known as "twisting". In order to prevent this, the thrower again raises and lowers successively the mass of body, appearing at certain times to desire to destroy what has just been done. He must also know how to well regulate the speed of the wheel to the ascending or descending movement which he gives to the body with his hands. He must then by suitable sprinklings prevent the body from drying unequally in contact with the fingers.

The thrower places on the table in front of him a model of the object to be made, which he imitates according to his judgment.

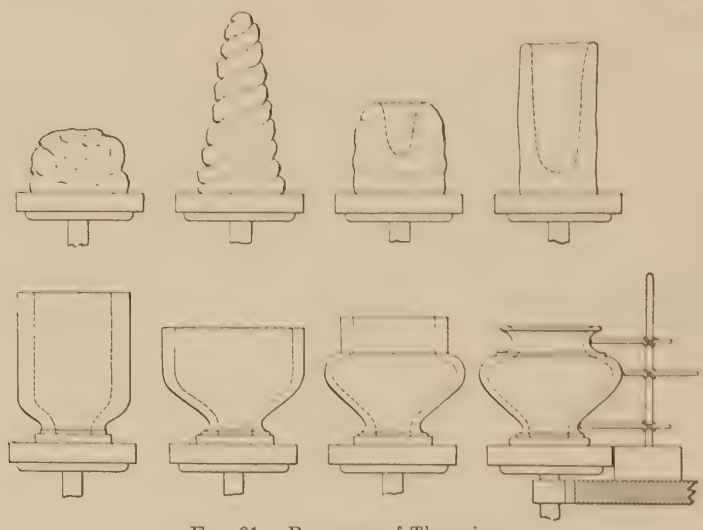


Fig. 61.—Processes of Throwing.

For the principal measurements he uses an instrument called a gauging rod, consisting of a vertical rod fixed on a stand and holding horizontal rods (Fig. 61), which indicate at the same time the height and the distance from the side of the wheel head. When the object is finished the thrower detaches it by passing an iron wire between it and the top of the wheel, then he removes it and places it on a board to be taken to the drying room. When the object is too heavy to be thus removed without risk of throwing it out of shape, it is turned on this board previously fixed on the wheel head.

Fig. 61 shows the throwing of a vase, and Fig. 62 that of a flat piece, a cover, in the example chosen. After having raised the

body in the form of a cylinder, the thrower opens it on top by widening it and by reducing it gradually to the desired diameter; then he makes the brim, the knob, and finally separates, by means of a wire, the object made from the mass remaining on the wheel. In doing this he has taken care to catch hold of the cover with the hand, then he turns it upside down and puts it on a board.

Examples could be multiplied, but the preceding will be sufficient

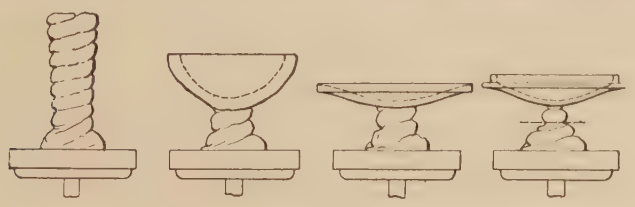


Fig. 62.—Processes of Throwing.

to show the principle of throwing, which in its details differs with each worker. Clever throwers are usually very proud of their knowledge, and they like to make in public difficult pieces, such as vases, narrow at the top, or even completely closed, as, for example, money-boxes.

The making of these pieces naturally requires very plastic bodies, like those generally used in the manufacture of terra cotta, stoneware, or faience ware. When the bodies are open, as in those

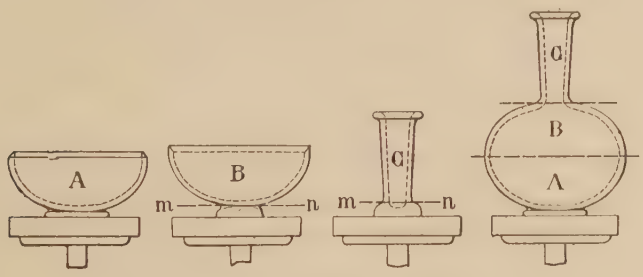



Fig. 63.—Processes of Throwing.

of porcelain, the most complicated pieces should be made in several parts which are afterwards soldered together. Fig. 63 represents the moulding of a decanter in three pieces. The parts to be joined are levelled in order to increase the surface of the joint. Usually the thrower makes several pieces of each kind, then, when the body is a little stiffened, he brings the parts together, after having wetted the joint with a sponge.

In certain cases, for rather massive pieces in which inside shapings have to be made, the process called "throwing by cord" can be used, as represented in Fig. 64. Round a fixed rod on a wooden plank a cord is rolled with varying thicknesses according to the interior space. Then the body is applied on the cord, the exterior outline is given on the lathe, then, after having allowed the body to harden a little, the end of the cord is pulled, which unwinds and comes off entirely, leaving a space corresponding to the place it occupied.

When it is desired to obtain pieces having a more rigorous form, a "profile" is sometimes used, that is to say a plaque in which the outline to be made is cut out. By means of any mechanism this

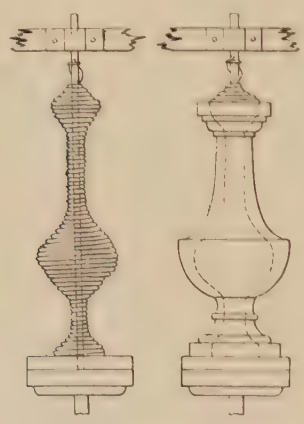


Fig. 64.—Processes of Turning.

Fig. 65.—Template.

profile is brought gradually to approach the piece thrown on the lathe, it removes the superfluous body and produces an object having the exact form of the profile. Fig. 65 represents a profile used for making the baluster, of which we have just shown the "cord throwing" (Fig. 64).

It must be observed that a complete "profile" of this kind can only be used when the piece to be thrown is upheld inside, as in the case Fig. 64, because the body is too soft to resist of itself, without losing its form, the lateral pressure exercised by the "profile". But the thrower can make use of small tools of metal, wood, slate, or horn, to give more precision to the moulding, to sink certain contours, or to sharpen the edges.

The throwing is generally completed by smoothing the sur-

faces with a small sponge, lightly applied, and by polishing them with a steel or horn blade.

Oval or square pieces can also be obtained by throwing.

For this purpose, the object is given a round form, then, after having allowed the body to harden a little, it is put out of shape by pressing the hands at the extremes of the same diameter. This process is now used no longer except for fancy articles, pieces of this kind being manufactured with much greater precision by means of moulds.

**101. Turning.**—Turning is employed in two cases :—

(1) For making objects in a plastic body, to which it is desired to give a very exact form, with fine and careful mouldings.

(2) For making objects in a body which is not very plastic, to which a good thickness must be given in the throwing, because of its feeble cohesion.

In the first case, the turning is only a kind of shaping ; in the second case, it is a real making, the throwing only having been able to produce a rough outline.

The turning is proceeded with when the body is sufficiently hardened, so that it cannot lose its form, but is yet soft enough to allow the nail to make an impression.

The turning being done when there are a certain number of pieces at the desired degree of dryness, it is necessary to keep the latter in a place having a constant humidity, a cellar for example.

The lathes used in turning are of two kinds ; vertical lathes and horizontal lathes. For vertical lathes, potter's or mechanical wheels are used, which have been previously described. The objects to be turned are fixed on a wheel head, by means of a shank, exterior or interior, according to the shape of the piece. This shank is often made by throwing on the wheel head a mass of stiff clay, and by turning the latter in order to give it a form capable of fixing the object either externally or internally. The humidity of the body is sufficient to hold together the piece to be turned after it has been lightly pressed. Some props, which are moved according to the height to which it is desired to work, serve as a support to the hand of the turner.

Horizontal lathes are similar to those used for turning wood or metal. Either the turner sets them in motion by means of a pedal, or an apprentice, or a motor, by using for this purpose one of the arrangements previously described for vertical wheels.

Fig. 66 represents a lathe of this kind, the speed of which is variable by means of a disc. A movable support, fixed on the bench of the lathe, serves as a resting place for hand tools. The latter are small blades of steel, to which are given by the file the most diverse forms, and which are fixed to a wooden handle. A pair of compasses or calipers are used to measure the diameter or thickness of the object. Turning is an easier

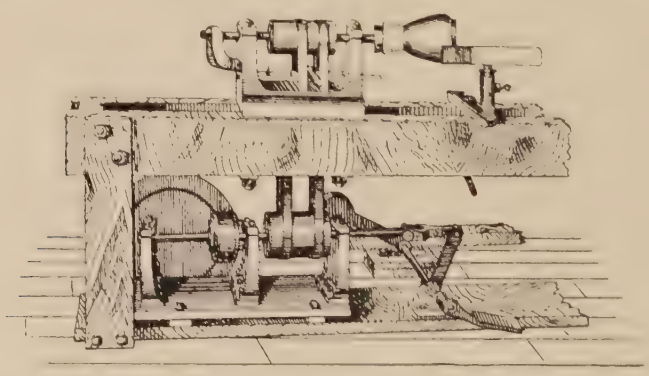


Fig. 66.—Turning Lathe.

operation than throwing, and can be quickly learnt by any thrower. It is sufficient to indicate that the body must be cut rather than scraped, and that when it becomes too dry, and consequently apt to break, it should be damped with a fine sponge. The piece being finished, it is polished with a steel or horn blade.

The chips and dust which fall during the turning are gathered up and placed again for manufacture. When the bodies must be worked while rather dry, which is chiefly the case with porcelain, there is produced, during turning, dust, which is very disagreeable and injurious to the health of the workers. The latter then should be provided with masks, or, better, a ventilator should be arranged which sucks in this dust.

(*b*) *Expression.*

**102. Dies.**—Expression is employed for making objects of a cylindrical or prismatic shape.

It is done by means of machines consisting of three essential parts :—

(1) The *die*, or aperture of a given section, through which the body is forced to extend itself.

(2) The *propeller*, or mechanical part, for compressing the body.

(3) The *cutting apparatus*, on which the cylinder, or prism of clay is received after coming out of the die, and where it is cut to the desired length.

When the objects to be expressed have a simple section, the dies are simply formed by a metallic slab or a board of hard wood, in which is bored an aperture having the form of

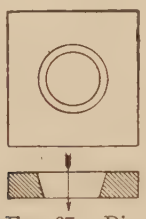


FIG. 67.—Die.

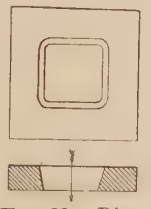


FIG. 68.—Die.

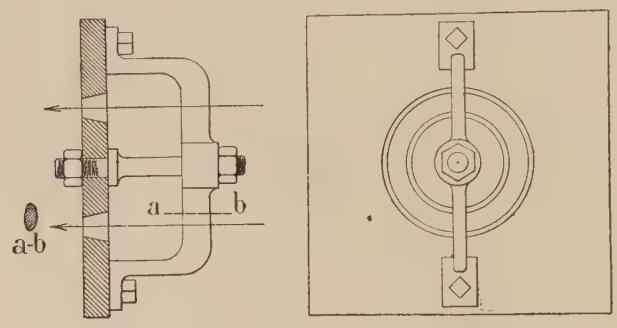
the object to be obtained. It is sufficient to slightly widen the opening at the side of entry of the body, to slightly round the angles, and to smooth well the walls of the aperture. Figs. 67 and 68 show some dies, one for expressing a cylinder of clay and the other a prism with square section, having at the greatest 2 in. to $2\frac{1}{4}$ in. diameter or side. The widening is from $\frac{1}{10}$ to $\frac{1}{5}$ of the thickness of the slab.

The same arrangement is also used when the objects to be expressed are hollow. There is then placed before the aperture a piece called a "bell," having the section of the space, and upheld by means of a rod and an iron bridge.

Fig. 69 shows an arrangement of this kind used for the making of pipes. The iron bridge must be placed far enough from the aperture of the die (6 in. to 12 in.), so that the body divided by it may be joined again under the influence of the pressure of the propeller and of the contraction which it experiences by its

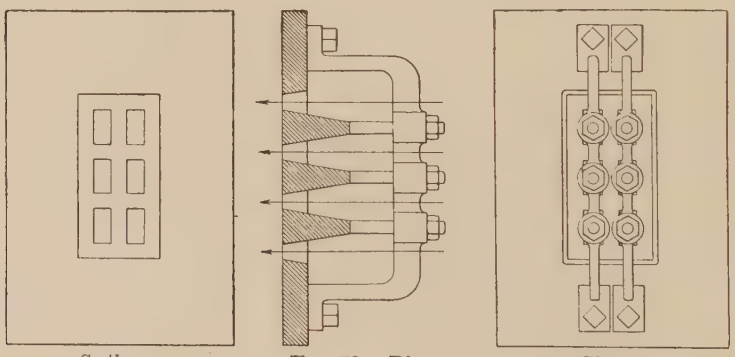
expression through the die. In order to divide the body as little as possible, the section indicated by the line *a b* is given to the bridge.

When the object to be made must have several spaces, "bells" corresponding in number are placed, and are upheld by one or several bridges. Fig. 70 represents the arrangement employed for the expression of bricks with six holes.




Section. FIG. 69.—Die. Plan.

The construction of dies becomes a more delicate matter when the objects to be expressed are solid, being more than 2 in. to $2\frac{1}{4}$ in. along the side or across the diameter. It is indeed easy to understand that if the expelled body is admitted into the die by a uniform pressure it produces a friction along the walls,



Section. FIG. 70.—Die. Plan.

which consequently retards the movement of the body. Thanks to the cohesion of the clay, this resistance is transmitted to the whole of the mass, where the orifice is not too large but beyond a certain limit the body, instead of advancing uniformly, has a tendency to proceed more quickly at the centre, and, on the contrary, less rapidly on the surfaces and especially at the

corners. When the defect is not too marked, differences of density result, which, at the time of drying and firing, cause the ware to lose its truth of form. If the fault is great, broken roughness at the corners is produced, as shown in Fig. 71.

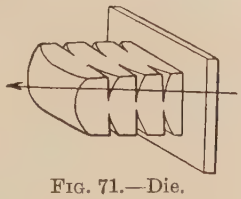


Fig. 71.—Die.

In order to remedy this defect there are two solutions: to increase the resistance at the central parts by diminishing it as much as possible at the angles, or to almost completely suppress the friction in the die by lubricating it.

Fig. 72 represents the first solution. Some *checks* of cast iron are brought outwardly to the die. They have the greatest length at the centre of the upright parts, and disappear at the angle. In this case the dies are often of phosphorous bronze.

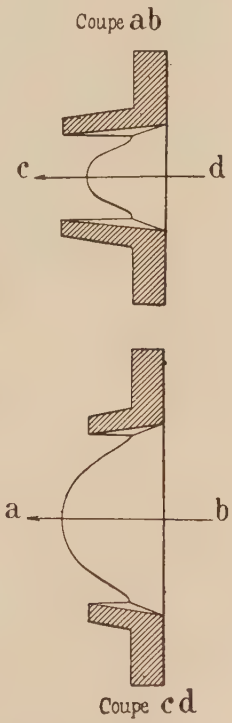



Fig. 72.—Die.

In the second solution lubricating is done

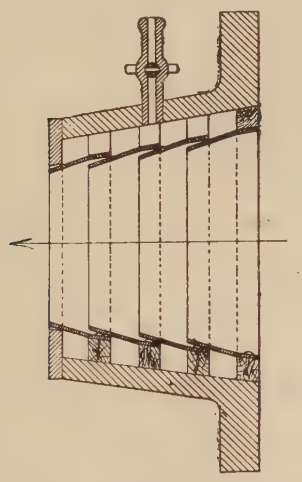


Fig. 73.—Water-lubricated Die.

with water contained in a vessel a little above the die, and in communication with it by means of a pipe and a tap which can regulate the introduction of the water. The difficulty consists in finding an arrangement which will let the water flow uniformly over all the surface without the orifices for the entry of the water being stopped up by the body. Many arrangements, more or less fulfilling this purpose, have been proposed. It will be sufficient

to indicate that which is now most employed and which is represented in Fig. 73.

In an exterior conical box are placed several wood frames forming a series of circular pipes, communicating with each other and with the tap for entry of the water by the upper part. On the frames are fixed some plates of zinc, which are placed above each other, and between them the water can flow in a very thin layer. This method is especially used for the making of articles of large dimensions, while the first is employed for expressing large wares, but relatively not very thick.

Generally speaking, the construction of dies is rather delicate, because their different proportions depend on the plasticity and consistency of the body used. Ceramists therefore would not do well in this matter to refer themselves entirely to the builders of the machines; they should themselves study the forms best suited to their requirements.

**103. Propellers.**—There are five classes of "propeller" presses, which are distinguished by the form of the medium of propulsion.

1. *Piston propellers.*
2. *Blade propellers.*
3. *Single screw propellers.*
4. *Twin screw propellers.*
5. *Cylindrical propellers.*

Fig. 74 shows the principle of the *piston propellers.* In a box

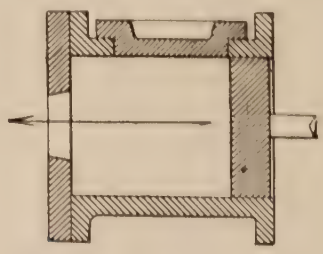


FIG. 74.—Piston Plunger.

bounded on one side by a die and on another by a piston, the body to be expressed is introduced through an aperture closed by means of a cover, so as to fill it completely. The piston is then set in motion, in the direction indicated by the arrow, thus causing the body to force itself out through the die. When the piston has

reached the end of its course it is brought back and the operation is repeated. The working is therefore intermittent.

The, movement of the piston can take place horizontally, as is seen in the machine represented by Fig. 75. In this case the mechanism is nearly always moved by hand. This arrangement is only employed for making hollow bricks or small pipes for a small production. Fig. 76 shows, on the other hand, an arrangement in which the piston is moved vertically; it is used for the expression of strong pipes. In this case the motion is given either by hand, or by a pulley, or finally by placing a cylinder moved by steam on the top of the cylinder enclosing the body.

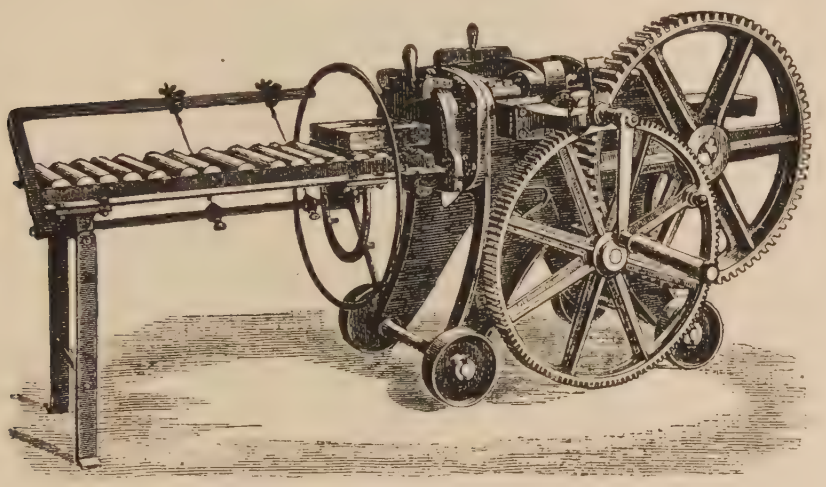


Fig. 75.—Piston Plunger.

*Blade propellers* are pug mills similar to those described in Chapter III. (Figs. 30 and 31), the door of exit of the pug mill being replaced by a die, and the lower *blades* serving as propellers. Fig. 77 represents a machine of this kind moved by hand. The body is thrown into the upper orifice of the pug mill. Its exit is made by intervals corresponding to the passage of each *blade* in front of the die. This irregularity in the movement, together with the necessity of only employing very soft bodies, prevents this kind of machine now being used except in small brickfields or for the making of solid bricks with very silicious clays.

*Single screw propellers* are, on the contrary, very frequently used. They consist (Fig. 78) of a cylinder, one end of which is closed,

while the other is provided with a die. In the interior is moved a screw, the spindle of which goes through to the bottom and is kept there by a projecting ledge. The body, introduced by an

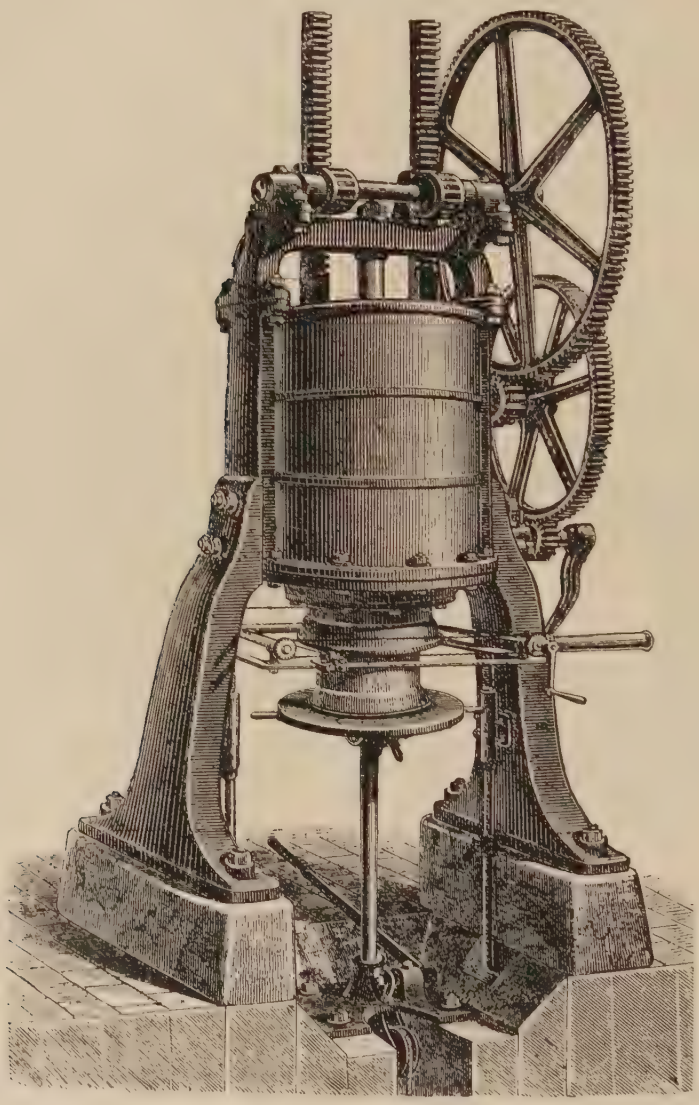


FIG. 76.—Piston Plunger Machine.

aperture above, placed at the back, is progressively compressed towards the front and compelled to force itself out.

It is seen therefore that there must be a certain relation between the diameter of the cylinder, the passage of the screw, and the orifice

of the cylinders. If for a given propeller this orifice is too large, the body, being introduced in the form of clods more or less rough, does not agglomerate and spaces will remain. If, on the other hand, the orifice is too small, the whole of the body introduced

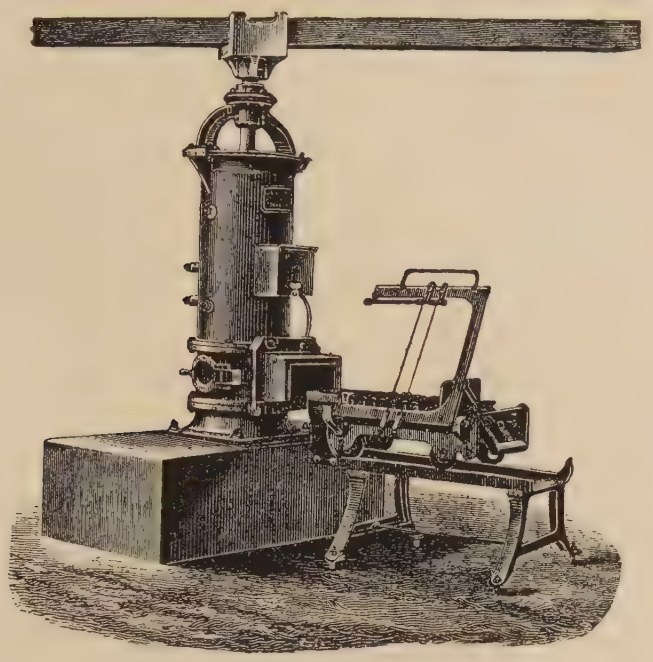


Fig. 77.—Combined Pug Pipe Machine.

cannot force itself out, the screw is choked up and eventually draws the mass in its rotatory movement, suppressing all propulsion.

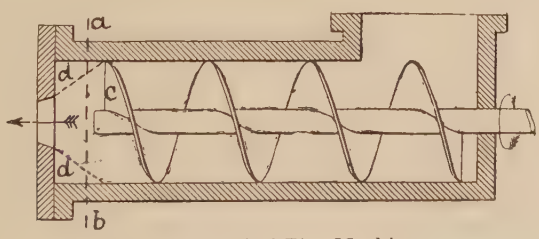



Fig. 78.—Spiral Pipe Machine.

Moreover, if the section *ab* is considered (Fig. 78), it will be seen that the pressure there is not constant. Each turn of the screw brings a fresh quantity of body which is chiefly pressed at its extremity, *c*. At any point of the section *ab* the pressure is there-

fore greatest when the generator, *c*, of the screw is in its nearest position, and least when in its furthest position. To avoid this difficulty, which would cause irregular expulsion, a certain distance is left between the screw and the die so that the pressure may become uniform by reason of the cohesion of the body.

This distance must itself be sufficient to fulfil the purpose proposed, and not too great, so as not to increase the resistance in considerable proportion. It must in fact be taken into account that the body remains motionless in the corners *d d*, and only advances in the form of a cone, having for a large base the circle engendered by the screw, and for a small base the orifice of the die. The friction which is produced between the body which is not in

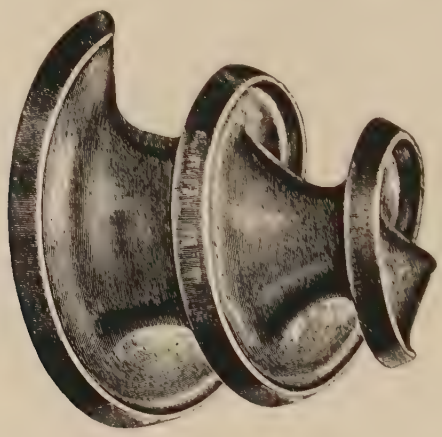


Fig. 79.—Worm Propeller.

motion and the propelled body is very great and can quickly stop the working if the height of this cone body is magnified.

This difficulty of screw propellers can be greatly decreased by giving to the end of the cylinder a conical form, and by giving to the screw a kind of spiral ending, also conical (Fig. 79). By this arrangement it is seen that the pressure is much less variable, and consequently allows the die to approach perceptibly nearer to the end of the screw.

Screw propellers are frequently combined with horizontal pug mills (Figs. 32, 33 and 34), the same machine being used at one time for pugging, then for expression. For this purpose the posterior part of the shaft is provided with "blades" and sometimes with *counterblades* (Fig. 34), while the anterior part carries

a screw in several pieces, or a conical helix, as it has just been stated.

Screw propellers are sometimes moved by hand, but only for very small output, and for goods of small dimensions; generally a motive power is employed.

Screw propellers are frequently used for the making of solid and hollow bricks, pipes, and usually for the *squeezing out* of all objects which are afterwards made by *press moulding*. They have the objection of requiring a rather considerable motive force, and of yielding wares which always have a helicoid structure.

*Twin screw propellers* are formed of a box containing two parallel screws, turning in a contrary direction and compressing the body by a single die. The object of this arrangement is to effect at the same time the pugging and the expression of the body. But the very relative pugging thus obtained, by means of the tangent screws, must not be confused with the much more efficacious action of the pug mill with two shafts, described previously (Fig. 35), the blades of which intersect each other. Considered from the point of view only of the making, this propeller has the disadvantage of giving rise to two parallel pasty currents, which the contraction of the *die* is not always sufficient to suitably weld together.

Figs. 80, 81 and 82 represent in vertical section, and Fig. 83 in horizontal section, the different arrangements adopted in *cylindrical propellers*. It is seen that the latter consist of two or three rollers seizing the body on one side and compressing it on the other in a box in which it has no other issue than the die. These propellers are simple, yield more homogeneous wares than the screw propellers by employing less force. The joining between the box and the cylinders is made on the one part by means of inlaid sheets fixed by bolts, which are brought in contact with the cylinders, and which are advanced in proportion to their wearing by some pieces, *b b*, which rub against the lateral surfaces of the cylinders, and which can easily be replaced. In spite of these precautions it is difficult to obtain air-tight joints. After working for some time, there are leakages of clay which make the machine dirty, and the removal of which is the chief, if not the only difficulty of these propellers.

The motion is always given by a motive force. Cylindrical propellers are used for the same purposes as screw propellers, although less frequently for solid bricks.

**104. Cutting Apparatus.**—At the orifice of the die the body makes its exit in the form of a prism having the section of the objects to be obtained, but which has to be cut to the desired length. For this purpose, this prism of clay is received on a bench provided with rollers of plaster or wood covered with felt. If the propulsion

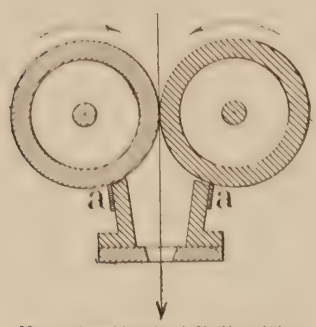



Fig. 80.—Vertical Roller Die.

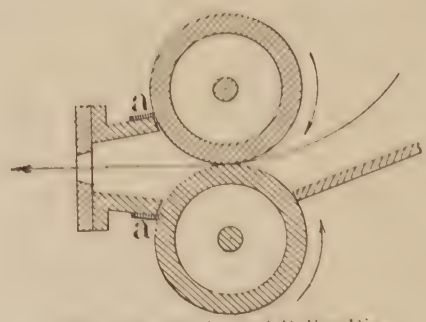



Fig. 81.—Horizontal Roller Die.

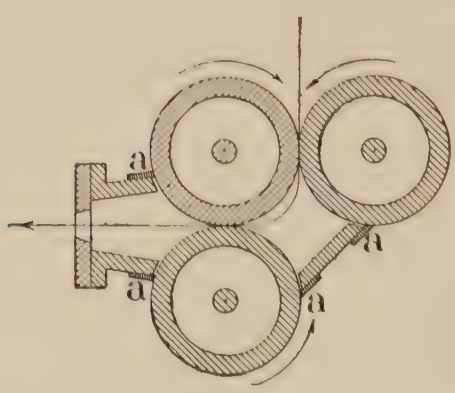



Fig. 82.—Compound Roller Die.

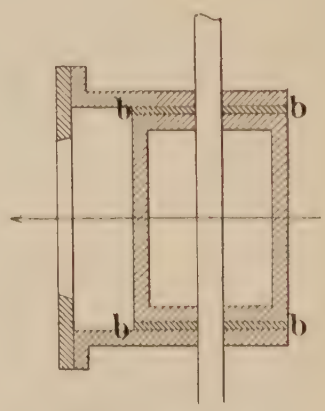



Fig. 83.—Plan of Fig. 81.

is done in an intermittent manner, or if the propeller is arrested at the time of cutting, it is sufficient to employ an apparatus with fixed cutter, shown in Fig. 84. The latter, besides the "roller bench" properly so called, consists of a metallic frame, on which are stretched steel threads passing between two rollers and having between them a distance equal to the length of the articles to be obtained. When the prism of clay is at a stand-still, a workman seizes this frame, which turns round two lower pivots, and draws it

to him by forcing the threads to pass through the mass of body, thus dividing it into pieces which are removed by hand. The frame is then replaced in its original position.

When the propulsion is continuous an apparatus with movable

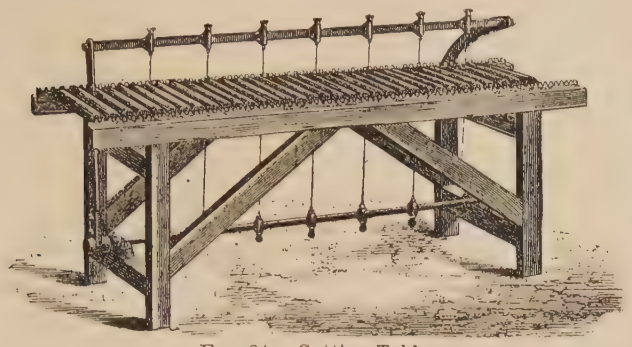


Fig. 84.—Cutting Table.

cutter must be used. The latter (Fig. 85) consists of one bench with fixed rollers and a second mounted on four wheels, which can be moved on two rails. The prism of clay is placed on the first bench, then passes on the waggon which has been brought in contact with it. The body tends to draw the carriage with it, but the

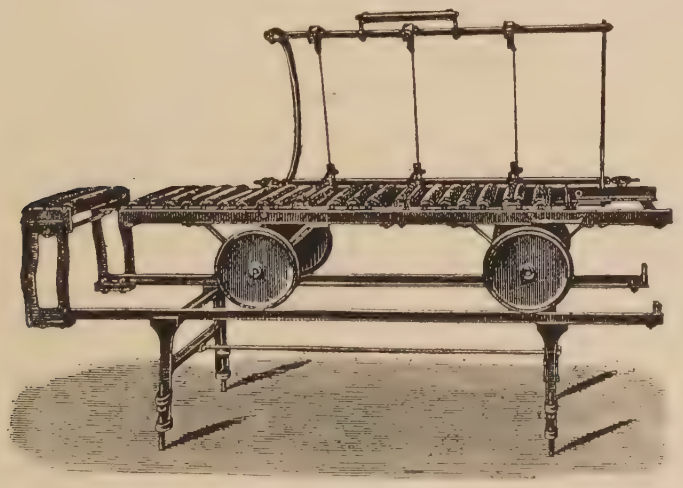


Fig. 85.—Cutting Table.

cutter workman keeps it until the prism of clay has reached the end of the waggon. He then ceases to stop it, and it advances with the same speed as the body, and he profits by this joint liability of motion to set the frame to work, which has the steel wires, as in

the fixed cutting apparatus previously described. The articles cut are then removed and the workman brings the waggon back in order to replace it in its original position.

When the propulsion is affected from top to bottom, as represented in Fig. 86, the body is received on a balanced table which descends until the instant that the prism reaches the desired length. The propulsion is then stopped and an horizontal frame is set to work, on which is stretched a steel wire. The cut piece is removed, and the table returns to its original position under the influence of a counter weight.

### (c) *Moulding by Hand.*

**105. Moulding with Wooden Moulds.**—When the objects to be moulded by hand are geometrical in form, plane surfaces of great

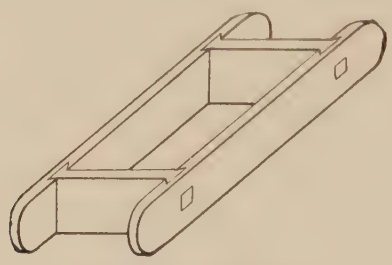


FIG. 86.—Wooden Mould.

thickness, wooden moulds are used in which the body is compressed. These moulds can be in one or in several pieces, according to the form of the object.

The most simple case is the moulding of ordinary bricks, which is done in wooden frames (Fig. 86) having an interior space corresponding to the form of the brick to be moulded. This frame is placed on a wooden table, then the moulder takes a quantity of body, slightly more than what is necessary, throws it violently into the mould, compresses it to fill the lower corners, then equalises the upper surface with a rake. The moulding is done by raising the frame and by pressing, if there is necessity for this, on the upper surface. As the body used must be very soft, the mould and the surface of the table are damped in order to prevent adhesion. For the moulding of bricks are also used metallic hinged moulds, but this special process of making will be described in Chapter IX.

The same process can be used for moulding bricks of all shapes and all dimensions, as well as tiles, plaques, etc. In order that moulding may succeed well, the body must have the desired degree of plasticity, should not be too soft and should well fill the mould, particularly the lower angles.

When the objects have a less simple form, as is frequently the case for refractory fired bodies, the moulds can be made in several different pieces. They then resemble the moulds used in foundries, the sand being replaced by a body sufficiently firm in order to be moulded by wooden rams of suitable form. In Chapter X. will be found examples of this kind of making.

If the object must have intricate grooved parts, or which would require too complicated moulds, they are first made roughly, or solid; then, when the body is sufficiently hardened, shaping is resorted to by means of different manual tools. If the body has not too coarse a grain, this operation is done easily, clay of hard consistency or demi-hard lending itself very well to carving by means of cutting sheets, or stretched steel wires.

**106. Plaster Moulds.**—When the objects to be made are not geometrical in form or are ornamented, plaster moulds are used, either in one or several pieces. Plaster is in fact the only material which can be practically utilised, since, owing to its porosity, it does not adhere to the clayey body, always rather soft, which must be used in moulding by hand. Formerly moulds in biscuit were used, but they have been abandoned on account of their more difficult and more laborious manufacture.

The plaster used must be good moulding plaster, which is sold in casks and must be preserved in a dry place. In some works it is found desirable to purchase the plaster stone; it is then pulverised and fired. The firing is done in sheet-iron pans heated from below. The temperature for firing the plaster is from 120° to 150° C. It is expedient to maintain the bottom of the pan at this temperature and to stir the plaster the whole time that the "dehydration" lasts.

The making of the moulds requires the use of a model representing exactly the object to be made, but slightly larger to allow for the shrinking of the body (see Chapter V.). Sometimes this model is an existing object in wood, metal, pottery ware, glass or ivory, which can be cast in plaster, after having been greased to

prevent sticking. If the object presented "undercut" parts, which would be opposed to leaving the mould, it would be necessary first to stop them up with some plastic body or with wax. These parts should be scooped out by hand after moulding.

Usually the object is formed specially in view of the ceramic reproduction. For all pieces of fine and distinct outlines it is cut out in plaster, and in modelling clay for pieces of a larger execution.

Plaster models must be greased or oiled before being cast. A solution of black soap and olive oil is also often used for the purpose. In order to prevent the plaster from absorbing too large a quantity of fatty substance, a layer of resin dissolved in alcohol can be first placed on it. Clay models do not require any preparation, but the humidity of the plaster deteriorates them, and they can only be used for a single casting.

The way in which the latter is done naturally depends on the shape of the model; sometimes the latter can be easily removed from the mould, but most often it is imprisoned, and the mould must be divided into several pieces before it can be taken out. This division is made either by cutting away the plaster, or by separating it by a stretched wire during its adhesion, or by first arranging sheets of pasteboard or metal at the joining places. When cutting is resorted to it is not necessary to push the wire cutter to the bottom; the latter being sufficiently advanced, a sharp blow is often sufficient to effect the rupture, according to the desired plan. In order to again join the pieces of a mould, their exterior surfaces are dressed, and an envelope of plaster is run all round. Examples of this arrangement will be given in the following paragraph.

The first mould obtained by casting of the model is only used for moulding when a small quantity of pieces is desired to be made. Usually it is called the "master mould," and is only employed to cast type models in plaster, which, in their turn, are cast to supply the working moulds. In fact, plaster moulds become the worse for wear rather rapidly, first in consequence of the constant humidity which is communicated to them by the body, and also because of the feeble resistance of plaster to blows or pressure.

This difficulty can only be partially mitigated by mixing the plaster with a little water which has some alum in it.

"Original moulds" are preserved with care in a dry place, so the type models can always be supplied conformable to the original model.

**107. Moulding with Plaster Moulds.**—"Pressing" by hand in plaster moulds can be done in a single operation. In this case the moulder takes some small fragments of body, balls, which he applies against the mould with his hand, or by the aid of a sponge if the body sticks to the fingers. But it is often preferable to first make a rough form, which consists simply of one sheet of body of uniform thickness, called a "batt". The latter is generally made by placing on a prepared and humid table a mass of body corresponding to the size of the "batt" to be obtained. Sideways are arranged two rules or straight edges, the thickness of which determines that of the "batt". Then a roller of damp wood is made to roll on these rules, so as to stretch the body. The "batt" thus obtained is removed by hand and applied against the mould. When the latter has some very undercut parts, which would compel the "batt" to be too greatly compressed by sensibly diminishing its thickness, it is preferable to cut pieces corresponding to those parts, and to afterwards solder them by hand against the mould. For bodies which are not very plastic it is preferable to spread on the table which serves for the moulding of the "batt" a cloth, or better still a damp skin, which is afterwards used to remove the "batt" and to place it on the mould, without the risk of breaking it, which might happen if taken by hand.

When the objects to be moulded are round and widened at the top, the "batt" can be replaced by a thrown piece made on the wheel, having about the height of the piece to be moulded, and a fairly reduced diameter, so as to be able to enter into the mould. In this case the thrown piece is called a "cover," and the making is done by applying it against the mould either by hand or with a sponge.

The following examples, with illustrations, will enable the processes of moulding by hand to be better understood than all the descriptions:—

Fig. 87 represents a panel moulded in one piece. The plaster mould has ornaments inserted on the surface seen. The moulding is done by applying on the mould a "batt" of desired measurements, and by forcing it with the hand or with a sponge, to take the form of the mould. As the central part would lack some body if the latter is plastic, it is sufficient to add some of the latter by hand or to make that from the exterior parts flow back; if, on the contrary, it is open, pieces corresponding to the design are cut in the "batt," and are afterwards joined one

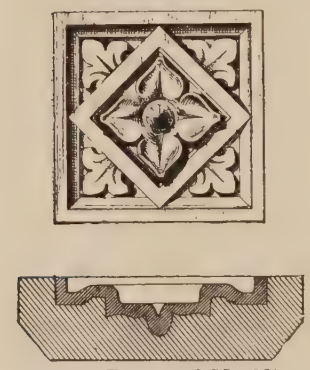


Fig. 87.—Process of Moulding.

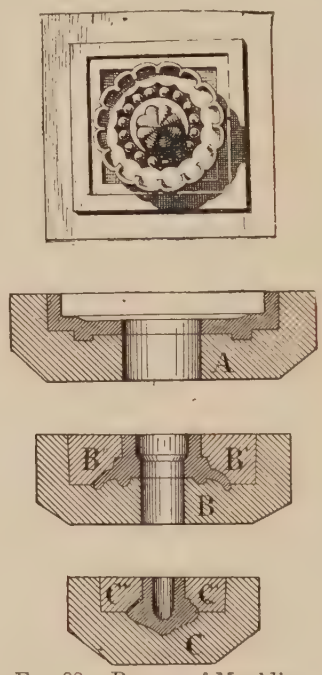



Fig. 88.—Process of Moulding.

against the other. The moulding being finished, the piece is left to dry in the mould; then, when it is detached, in consequence of its shrinkage, the latter is turned upside down, and the piece moulded is received on a board where it becomes dried.

Fig. 88 also represents the moulding of a panel of more complex form, for it must be made in three pieces. The first is moulded in the mould, A, as in the preceding case; one removes only with a knife the part of the "batt" which is found above the central aperture. The rosette is moulded in a case-mould, B, in which are two pieces, B′ and B″. In this case the

"batt" cannot be made use of, but the body is placed in the form of a cylindrical or conical mass, which is forced to penetrate into the empty space of the mould, then the two ends are joined, and the interior circular part is smoothed by hand. The emptying of the mould is performed as previously, by turning the mould upside down, by raising the case-mould, B, then by drawing sideways the two parts, B′ and B″. The central bottom is moulded in the same way, also in a mould in three pieces, C, C′ and C″. The three parts of the panel can afterwards be joined when the body is sufficiently hardened, but generally they are fired separately and joined together afterwards with cement.

When a piece which is seen on all its sides has to be moulded, as for example the Chimæra, Fig. 89,[1] it is moulded in two or several parts which are afterwards joined. In the present case, the model being symmetrical, the joining is naturally done in the plan. One begins by moulding the grooved pedestal, then in two separate moulds each part of the body of the chimæra. A cut made following the line *mn* shows the arrangement of the mould, which consists of a case, A, in which is placed a series of pieces, *a*, *b*, *c*, etc., distributed in such a way as to allow the emptying. The two halves of the chimæra are then moulded, as it has been previously indicated; after the drying they are taken out of the moulds and joined, first with each other, then with the pedestal. It is preferable to mould the tail by itself and also connect it. The preceding moulding is applied to pieces not having large dimensions; when this is not the case it is necessary to make the article in several pieces, which are fired separately and afterwards joined together with cement, as in the case of Fig. 89.

Examples could be multiplied, for each model should be studied separately for the purpose of determining the most suitable form to give to the mould and especially the position of the joints, which, on the one hand, must allow of emptying, and on the other, must not cut the delicate parts, as the face, for example, in a statuette, so as to avoid retouching there,

[1] The models of the chimæra, as well as those of the two preceding metopes, belong to MM. Perrusson fils & Desfontaines.

rendered necessary by the seaming of the joint. It is necessary also to take into consideration the shrinkage during the drying, which must not be hampered by the form of the mould, and, lastly, the resistance of the pottery to the firing and for its ultimate use. The preceding examples are sufficient, however, to show the principles on which is based the making with plaster moulds. It will be referred to again, moreover, in the special study of the different kinds of pottery.

The making of the moulds, which, as is seen, requires a thorough knowledge of the trade, is generally entrusted to specialists. As to the moulding itself, however simple it may

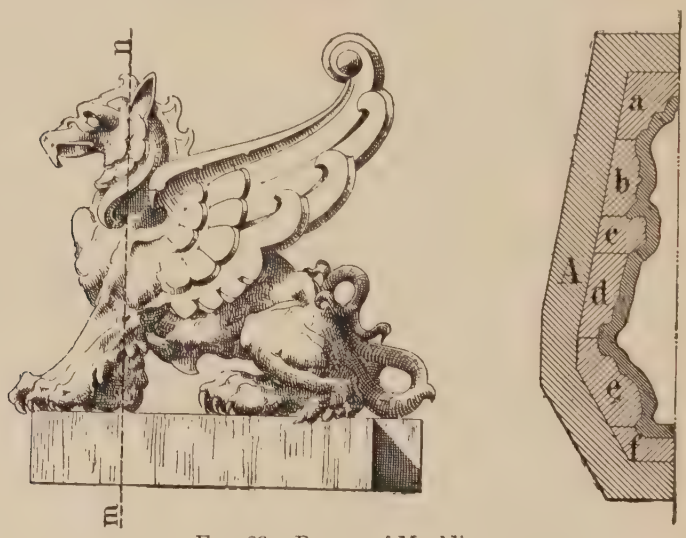



Fig. 89.—Process of Moulding.

appear, it also requires a certain amount of technical skill for the uniform distribution of the body, without which certain parts may be more compressed than others, so as to suitably effect the joining and the sticking the pieces brought together. Every defect, especially in the case of vitrified pottery, causes, during the drying and firing, warpings or ruptures.

### (*d*) *Moulding on the Jolley.*

**108. Jolleys, Moulds and Profiles.**—In moulding on the jolley, applicable to round or oval articles, the part of the piece which must be produced with the greatest amount of care, the interior or exterior as the case may be, is made in a mould placed

on a jolley, while the other is made with a profile. This moulding is done then by means of three essential machines, the jolley, the mould, and the profile.

*Jolleys* consist of a vertical shaft, similar to potter's wheels, which can be used for this purpose. However, as the force to be exerted is usually less great, the disc can be lighter and of a more reduced diameter. But the moulding on the jolley, being applied especially for the production of a great number of useful articles (plates, cups, etc.), mechanical lathes are generally used, one of the arrangements previously described being utilised for this purpose. In this case it is not necessary, however, to be able to modify the speed considerably, and also for articles of small dimensions (cups, flower-pots) it is sufficient to have a

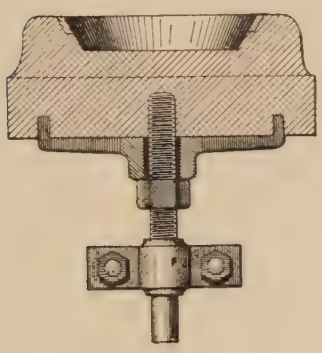


Fig. 90.—Jolley Head.

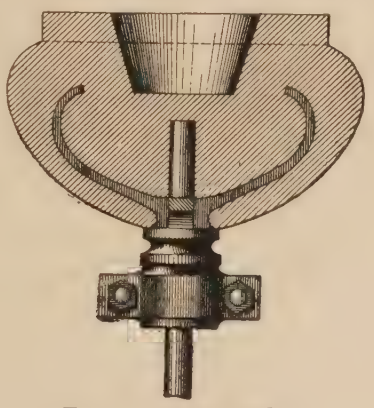


Fig. 91.—Jolley Head.

jolley of constant speed provided with a brake well within reach of the turner.

The heads of jolleys are arranged so as to receive the moulds, the placing and removal of which must be done very rapidly. For this purpose they have at the upper part a truncated space corresponding to a similar projection of the mould. A simple pressure is enough to fix the latter and to centre it. Figs. 90 and 91 represent the arrangements most generally adopted. In the first the head can be of plaster or wood, in the second it is always of plaster. The edge of the truncated space is often strengthened by a lead ring (Fig. 90).

Oval pieces can also be made on the lathes by using, for example, the arrangement shown in Fig. 92. In the latter the spindle of

the jolley is terminated by a metallic piece, in which slides a kind of rule, carrying at its centre the head and at its two ends some T's, the horizontal branches of which are obliged to slide the length of an eccentric circle, fixed by means of the iron pins on the table of the jolley. This eccentric imparts to the head a come-and-go movement which combines with the rotation of the jolley and in

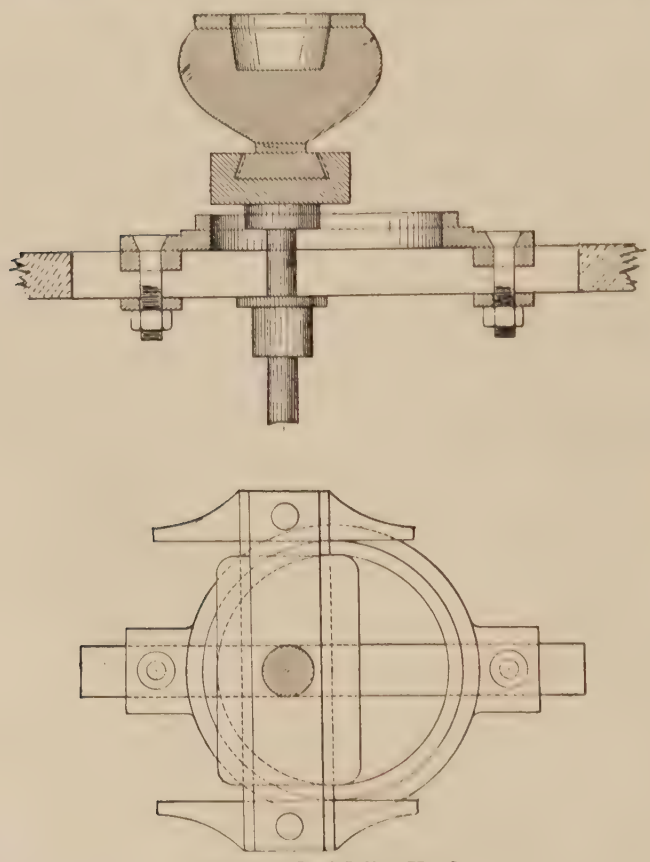


FIG. 92.—Oval Jolley Head.

reality makes it describe a kind of oval, the form of which is determined by the eccentricity of the conductor circle.

The moulds are made of plaster; they are in one piece for all flat objects (dishes, plates), as well as for those wide at the top (cups). On the other hand, it is necessary to make them in two and sometimes in three parts for objects with narrow aperture. In all cases they are terminated at the lower part by a truncated cone intended to fit into the head. The examples of moulding on the jigger given

in the following paragraph will show the arrangements generally adopted.

*Profiles* are rather thick sheets cut so as to remove not only the excess of body, but also to press the latter against the mould, as represented theoretically in Fig. 93. They are of steel or sometimes

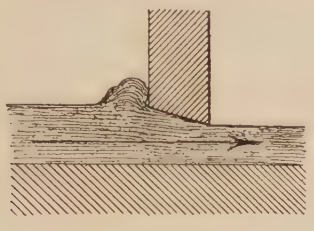


Fig. 93.—Profile Tool.

of strongly fired body (faience or porcelain body), which are shaped with files in order to give the suitable profile to them.

The way in which the profile is brought in contact with the body depends on the form of the object to be made. When possible, it is fixed to a support fastened on the table of the jolley and capable of turning round an horizontal axis. This support, in this case, is

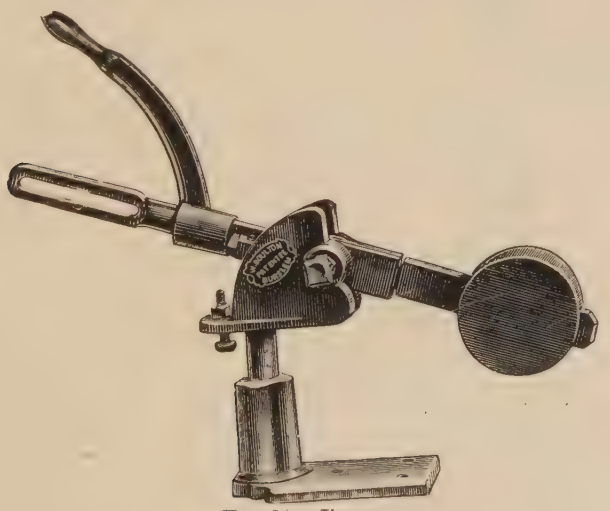


Fig. 94.—Jigger.

called a jigger. Fig. 94 shows the form of jigger most used for all objects which are flat or widely opened at the top. In other cases the profile is fixed to an upright, which at first allows it to descend in contact with the body, then makes it turn by means of a handle fixed on the vertical beam, as shown in Fig. 95. The

following examples will make the working of these apparatus understood.

**109. Processes of Moulding on the Jolley.**—This is only for plastic bodies and for common pottery ware of suitable shape (porringers, flower-pots, etc.), when the making can be done in a single operation. In this case the turner places in the mould a piece of body of a volume appropriate to that of the piece to be moulded, then he sets the lathe in motion and introduces the profile gradually. The latter compresses the body towards the walls of the mould, and, when it has reached the end of its course, leaves between it and the mould a space occupied by the body, which has exactly the section of the piece of pottery. But generally it is necessary to make a rough shape, that is to say a "batt" for the flat pieces and a form for the deep pieces. "Batts" are prepared as has been said in connection with the moulding by hand. One can also place on a table a block of body and cut the latter horizontally in slices of equal thickness by means of a wire, which is slid on the "rules" placed at the right and left of the block. These are generally iron "rules" placed one above the other, at a height nearly equal to that of the block. At first the wire is guided, by supporting it on the two upper "rules," then after having drawn away the piece detached from the top of the block, a "rule" is removed from each side, cutting is again proceeded with and thus is obtained a "batt," the thickness of which is equal to that of the "rules". Then the operation is continued by removing each time two "rules."

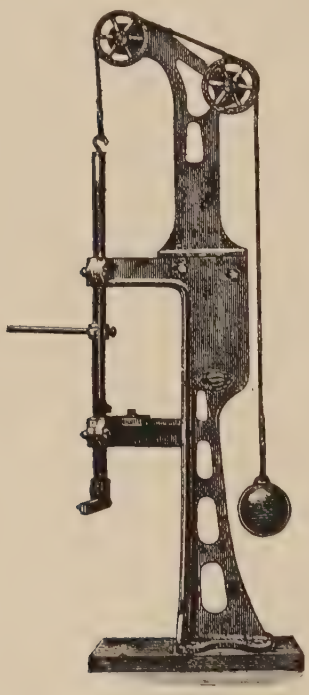


Fig. 95.—Upright Jolley.

For pieces requiring care (plates, dishes, etc.), which must have a compact body free from bubbles, it is preferable to make the "batts" on the jigger. In this case, the head being replaced by a disc (Fig. 96), there is placed on it a piece of body which is equalised in the form of "batt" by means of a profile mounted on an arm.

When the body is very open (porcelain) the arrangement shown in Fig. 97 is preferable, in which the head is mounted on a wooden ring covered with a stretched skin. The profile, which is of helicoid form, descends vertically, and, the "batt" obtained, it is removed with the ring.

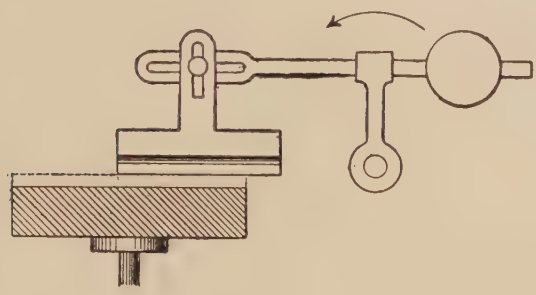


Fig. 96.—Batt Making.

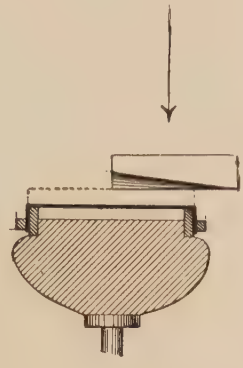


Fig. 97.—Batt Making.

As for the "batts," they are made on the potter's wheel or a mechanical lathe, by the processes indicated previously.

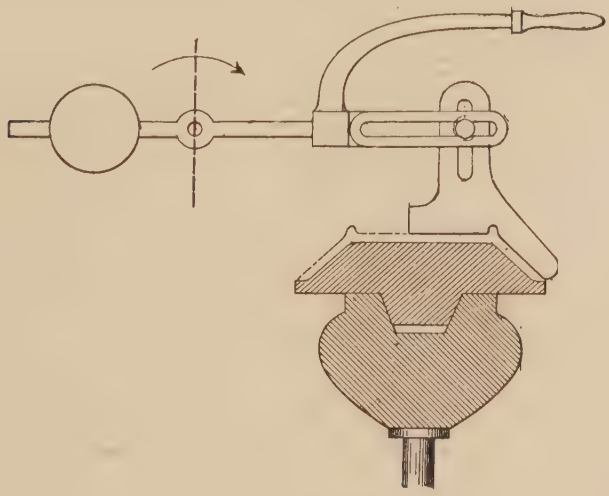


Fig. 98.—Jiggering.

The thrown piece, "batt" or "form," being thus made, it is placed on or in the mould, and the jolley being set in motion, it is led to adopt the form of the mould. It remains then to make the free surface, which is done by drawing near the profile.

Fig. 98 represents this operation in the case of the making of

a flat piece with a fairly plastic body, as that of faience. Then Fig. 99 shows the moulding of a deep piece. In these two arrangements it is necessary to place the profile in such a position that it begins to lean to the centre of the piece so as to drive the excess of body towards the circumference. When the pieces of pottery have a convex shape this process is no longer applicable, and the following example (Fig. 100) shows one of the arrangements which can be employed. The profile is suspended at the end of a prop at the end of a beam slightly eccentric in relation to the axis of the jigger. When the profile is in the position shown in plan A A′, it can be introduced by the narrow orifice of the piece of ware; if it is then

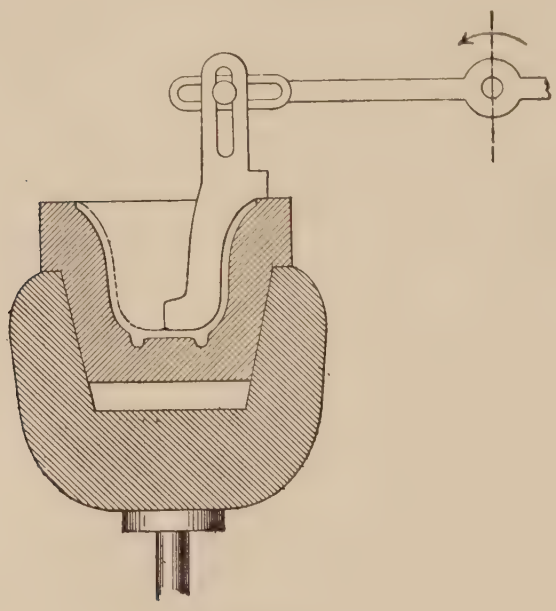


Fig. 99.—Making by Jolley.

made to describe a quarter of a circle it takes the position B B′, which puts it in contact with the body. To allow of the emptying, it is necessary to make the mould in two parts.

In the same manner as in moulding by hand, it is necessary in the moulding by jolley to adapt the mechanism to the particular shape of each piece; but the preceding examples are sufficient to show the general principles of this mode of making.

When the body is very open, which is usually the case with porcelain, the first difficulty is met with in obliging the piece

to assume the form of the mould, especially if the latter differs perceptibly from that of the piece. Sometimes a special machine

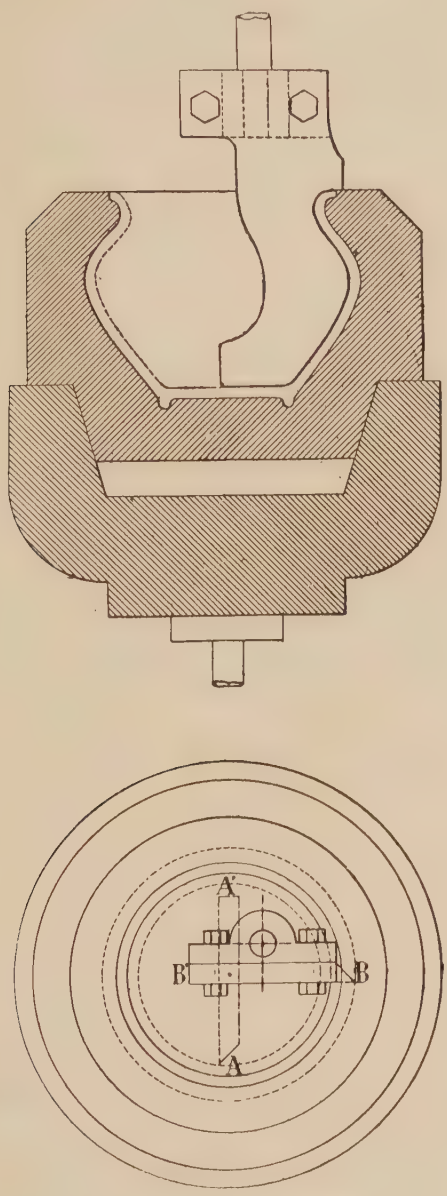



Fig. 100. Making by Jolley.

is resorted to, which serves to make use of the thrown piece before the employment of the profile; it will be spoken of when dealing with the special manufacture of porcelain. The second

difficulty is found in the use of the profile itself, which demands a certain plasticity of body. If the latter is insufficient, and at the same time slender articles have to be manufactured, the profiling has sometimes to be dispensed with and the following process adopted: the piece, to which is given a thickness considerably greater than is necessary, after having been applied on the mould, the latter being fixed on the jigger, is left to dry; then it is taken out, and the making is finished by means of turning. The latter is effected on a vertical or horizontal lathe, according to the form of the ware, as has been seen previously. In this case the turning constitutes the chief operation in the making, it must not therefore be confused with the operation of finishing, which will be dealt with later. The body being already rather dry, the turning causes a large amount of dust, which is seriously detrimental to the health of the workers; thus it is agreed, as has been already said, to draw it in by means of ventilators, or at least to provide the turners with suitable masks.

### (*e*) *Moulding by Compression.*

**110. Moulds.**—In *moulding by press* the body is compressed mechanically into the moulds. The stock of tools necessary for this process of making consists of two essential parts—the mould and the press.

The *moulds*, in spite of their diversity of shape, can be divided into two classes, according to the way in which the mechanical force acts on the body: squeezing moulds and compressing moulds.

*Squeezing moulds* generally consist of two parts, which, by coming together, squeeze the mass of body which has been placed between them, and force it to take the form of the space which separates them. The body in excess escapes as seam between the two parts of the mould. In afterwards removing the latter, the article made remains attached to one or the other; different methods are employed to detach this from it according to the form of the piece.

This mode of making permits the use of bodies of almost all degrees of consistency, provided that the article made does

not lose its shape in the taking out. When soft body is made use of, a plaster mould is employed by preference, or rather a metal mould covered with plaster in those parts in contact with the body. In this case plaster is, in fact, the only material which allows of an easy delivery. Where the body is stiff, plaster would not resist the pressure which must be applied, and it is necessary to have recourse to metallic moulds, which generally must be lubricated in order to prevent sticking.

The body, whether soft or hard, should be wedged before being placed in the moulds.

Fig. 101 represents the making of a tile in soft body by this process. Metallic moulds are provided with plaster inside. When they rest on each other the space corresponds exactly

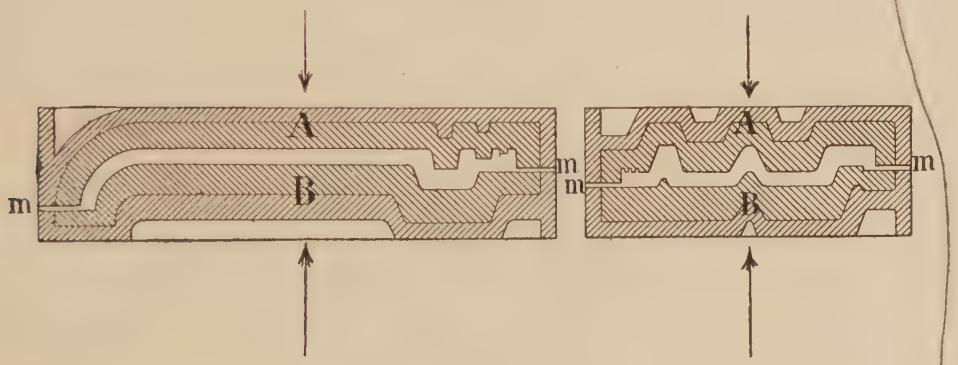



Fig. 101.—Making by Press.

to the form of the tile. The body is put between the moulds in the form of a "batt" or cake, having about the same dimensions as the tile, but slightly larger in volume. The excess of body escapes by forming seams along the surfaces in contact (*m*). The delivery is done by removing the moulds and by turning the lower mould upside down.

As a second example, Fig. 102 represents the moulding of a flower-pot in rather a hard body. The mould, entirely metallic, consists of three parts, A, B and C.

The parts B and C being in the position shown in the figure, and A being raised, there is placed in the mould a cylinder of body having a volume slightly larger than that of the flower-pot. A is lowered, the excess of body goes out at *m*, then A is again raised, and by raising the floor, C, the delivery is effected.

In the second part of this work other examples of moulds of this kind will be found, which permit the making of very diverse objects, especially if the moulds are made in several pieces so as to allow of the delivery of the undercut parts. The preceding examples are sufficient to show that for the whole time that the drawing together of the moulds lasts the body stretches itself out to follow the outline, and the excess makes its escape by flattening itself between the extreme edges. The force necessary to effect the moulding is that expended by the friction of the body sliding on itself, and on the walls of the mould. This force depends, therefore, on the consistency, on the quantity of body in excess, and on the form of the mould.

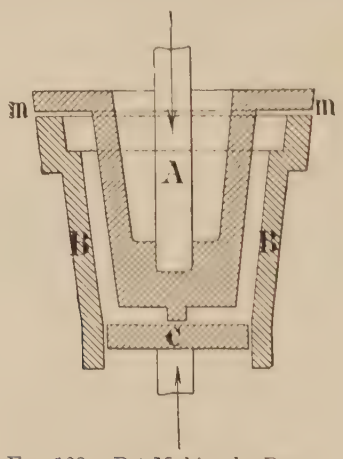



Fig. 102.—Pot Making by Press.

The consistency is often charged with other considerations, among which the most important is the necessity of avoiding deformation in the delivery. But, at the outset, only from the point of view of the making, it is not necessary to give to the body an exaggerated consistency, which not only occasions a greater expenditure of force, but, what is more serious, gives, in consequence of the flattening of the body, pieces of ware of a laminated structure, in which the different thin plates are insufficiently joined. The excess of body must be sufficient to ensure the complete filling of all the spaces; it depends necessarily on the form of the mould, and on that of the "wedging," but this condition being fulfilled it is not necessary to exaggerate it.

Lastly, if one considers what happens during the moulding,

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it is seen that in certain mould shapes, for example in the case of Fig. 101, some air remains imprisoned in the deep parts. This air is compressed, preventing the body from penetrating completely. This difficulty is greatly lessened by giving two, or even three, successive pressures, moving the dies a little each time to allow the compressed air to escape. Some air holes can also be pierced, but unless a very consistent body is used the latter have a tendency to become stopped up at each operation.

*Compressing moulds* consist of a box in which the body is placed, and this is afterwards compressed by a plunger entering and fitting there exactly. This making is done with a hard or dry body, the moulds being always of metal. The mould is sometimes in several pieces in order to allow of delivery.

Fig. 103 represents the principal arrangements of this mode

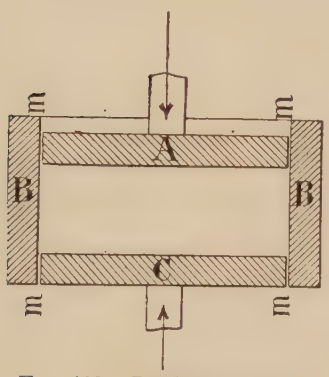


Fig. 103.—Die Box for Press.

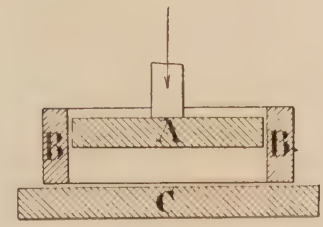


Fig. 104.—Die Box for Encaustic Press.

of making. The "batt" in a hard body, or the measured quantity of dry body, is introduced into the mould formed by the parts B and C, then the plunger, A, is made to descend. When the pressure is sufficient this latter is raised, then the delivery is carried on by raising the bottom, C. This bottom can also be made to descend by causing it to follow for some time by the mandrel, A, and effect the delivery from below. In some machines the mandrel, A, and the bottom, C, approach each other simultaneously in order to work the pressure, the delivery being effected afterwards as previously.

In articles of slight thickness, tiles for example, the arrangement shown in Fig. 104 is often preferred, in which the delivery is done by removing the part B from the mould. Lastly, for

more complicated shapes, this matrix can be made in several pieces. There will also be found in the second part of the work some special examples of compressing moulds.

The force employed to effect the moulding has, in this case, in reality first to force the body to fill the mould, and afterwards to compress it to the desired degree.

In adopting the method of making by compressing moulds there can be two different objects:—

1. To give an exact form to a mass, made generally by moulding in a soft body, after having allowed the body to harden and the greatest part of the shrinkage to take place.

2. To make in a single operation articles with a dry body.

In the first case only the shape can be improved, and not the quality of the ware, for the compression causes cracks in the body which are only imperfectly joined in consequence of the lack of plasticity.

In the second case the plasticity is replaced by a compression which must be the more powerful as the body is drier. But this object can only be partially obtained, for pressure can never impart to the flat molecules of clay the cohesion which they acquire by their mixture with a sufficient quantity of water. Moreover, the air which is found between the grains of the dry body cannot entirely make its exit by the joints of the mould or by the air holes which are arranged in it.

If Fig. 103 is referred to, it will be seen that the force of compression begins by acting on the upper parts of the body in order to spread nearer and nearer to the lower. The air contained in the latter cannot traverse the upper layer, which has already been rendered dense by compression: it is therefore found imprisoned in the form of flat bubbles, which separate the layers of body and prevent all adhesion. This serious difficulty can only be remedied by giving several successive pressures, each time allowing the imprisoned air to escape. Nevertheless, for very thick wares this remedy is insufficient.

Moreover, moulding with a dry body, which does not take into consideration the essential physical properties of the clay, would be entirely condemned if it did not in certain cases, by

means of the simplification of the preparation of the bodies, and by the suppression of the drying, enable the prices of the manufacture to be considerably diminished, although at the expense of the quality of the ware.

111. **Presses.**—The systems of presses are very numerous, and their complete description would be a veritable treatise on mechanics. Some general indications will therefore only be given here, interesting only from a strictly ceramic point of view.

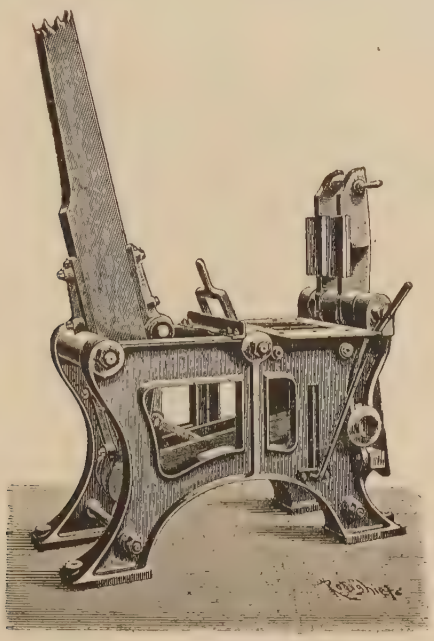

Fig. 105.—Lever Press.

The presses can act either by shock or by pressure.

In presses by shock it is necessary to accumulate, in the plunger and the mechanism which commands it, an active force corresponding to the work to be done. As the estimation of this work is too complex to be done by calculation, one can only render account of it by trials of the power of the press.

The movement is perforce intermittent, the mandrel or one of the parts of the mould continuing its movement until all the active force has been destroyed by the work of resistance. With squeezing moulds the stoppage is produced when the two parts

of the mould come in contact, the blow being chiefly mitigated by the seam of the body. With compression moulds it is the body alone which determines the stoppage of the plunger. In consequence it is very important each time to place in the same quantity of body, failing which the wares would present variations of thickness.

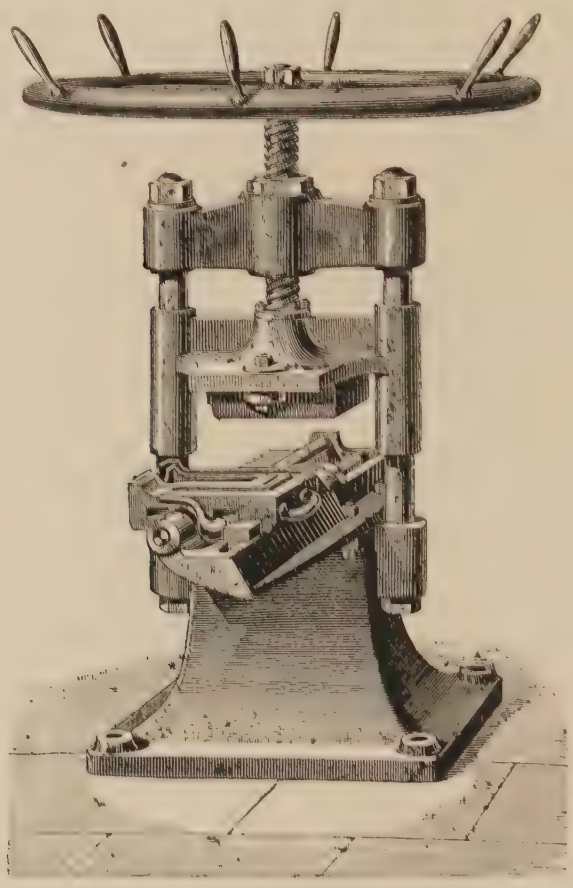

Fig. 106.—Screw Press.

Presses by shock must be employed when the power of the motor is not sufficient to give the desired pressure. This is especially the case with presses worked by manual labour. Figs. 105 and 106 show two examples of this kind. In the first, the man acts by exerting the weight of his body on a lever, which forces the bases of the moulds forming mandrels to rise, while compressing the body against the sides of these moulds. The

latter are represented open in the position which they occupy at the time when they are being filled with body; at the time of pressure they are brought down and held by a hook. The delivery is done by taking down the caps and by continuing to

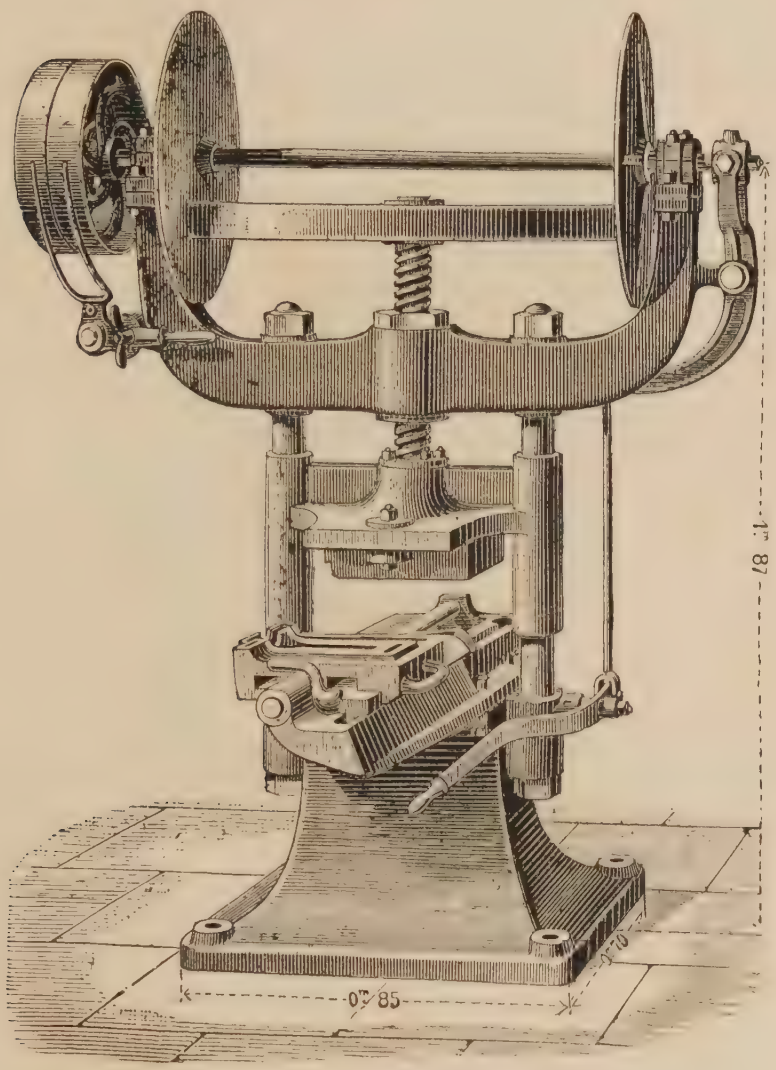


Fig. 107.—Machine Screw Press.

raise the bases by means of a lever. In the second, the moulder acts on a screw by the aid of a fly-wheel, which he hurls with force by means of handles. The screw carries the upper part of a mould, the second half of which can be displaced through

the length of a slide, in order to allow it to be turned upside down and to effect the delivery.

The same arrangement is often employed (Fig. 107) by working the fly-wheel of the screw by means of two discs set in motion by a motor, the one causing the screw to turn by friction in the direction of the descent, and the other in that of the ascent.

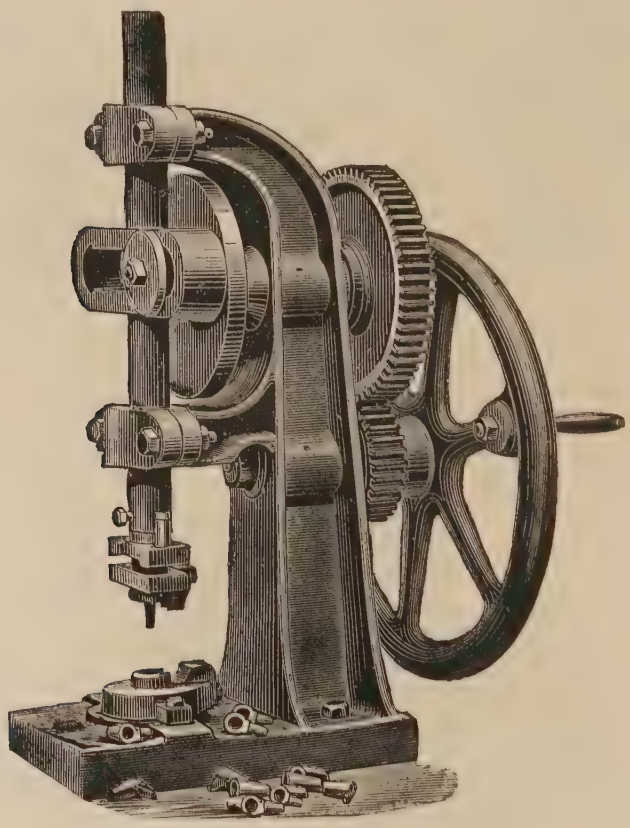

Fig. 108.—Excentric Press.

A mechanism, worked by a workman, or sometimes automatically, brings by rotation each disc in contact with the fly-wheel. The delivery can be done as represented in Fig. 119, or, indeed, by raising the base of the mould by the ascending motion of the screw.

Shock presses can be constructed by making use of other mechanical arrangements, for example, of stamping mills moved by cams, of excentric wheels worked by a fly-wheel, etc.

In *presses acting by pressure* the force of the motor is produced during the compression. This force can be calculated and the pressure exerted proportioned to the square inch of surface of the mould: the motion is intermittent or continuous.

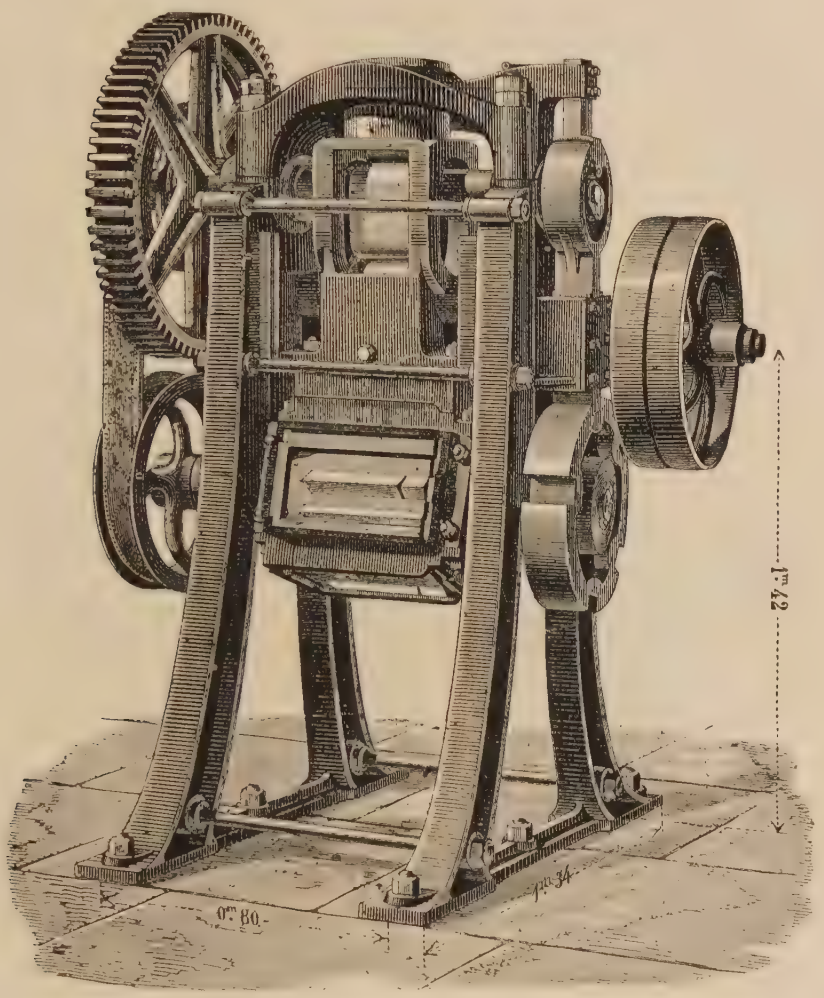


Fig. 109.—Excentric Tile Press.

The type of presses with intermittent action is the hydraulic press, the working of which is too well known for us to dwell on this subject. They are only used for the making of tiles, and in the chapter dealing with this manufacture will be found some details on their application in ceramics.

Presses with continuous action are usually based on the use

of cogs or excentric wheels, which, at each rotatory movement of the motor beam, give one or several increasing pressures.

When the articles to be made are of very small dimensions they can be worked by hand, as shown in Fig. 108, but generally they are set in motion by a motor. Fig. 109 represents a press of this kind used for the manufacture of tiles. The upper part of the mould receives by an excentric wheel an alternate motion from top to bottom. There are five lower moulds arranged on a framework of five sides (pans), which turns a fifth part of the circumference at each pressure so as to allow a cake to be placed at one side in a continuous manner, and to deliver at the

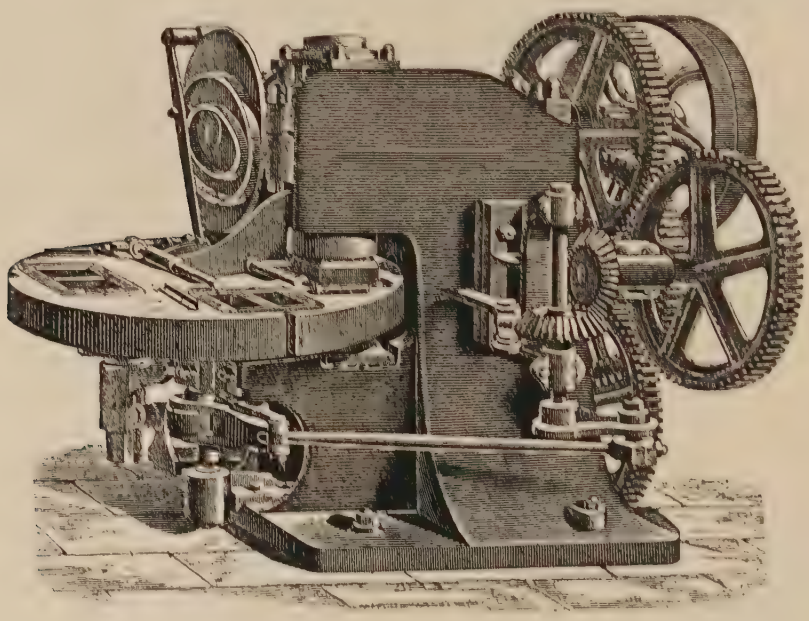

Fig. 110.—Quadruple Brick Press.

other the tile made. A side bolt holds this framework during the pressure.

Finally, as the last example, Fig. 110 represents a brick press with excentric wheels, working two twin plungers, while four pairs of moulds are arranged on a turn-table making a quarter of the circumference at each pressure. The delivery is done automatically, by the raising of the lower part of the moulds; analogous machines, based on the use of excentrics, cogs or levers, have been constructed after a great number of different

types, chiefly for the moulding of bricks in dry body. A description of some of these machines will be found in the chapter relating to the manufacture.

### (*f*) *Moulding by Slip Casting.*

112. If a dry plaster mould is filled with a liquid body, and if at the end of some minutes the remaining liquid is removed, the walls of the mould are seen to be covered with a more or less thick layer of the body, while a part of the water has been absorbed by the plaster. By afterwards leaving this body to become hard it can be delivered, and in this manner an article is obtained reproducing exactly the form of the mould, and having everywhere the same thickness.

But, in order that this deposit may acquire a sufficient thickness, it is indispensable that the body should not be very plastic, so that the absorbing action of the plaster may continue to be produced. With a plastic body, the first layer deposited forms a coating impermeable to the water. This process of making cannot consequently be employed except for certain porcelain bodies, or in a more general way for those having kaolin as a base.

The body should be extremely fine, and very well prepared. It is expedient, before using it for moulding, to separate from it all air bubbles, and, for this purpose, to make it pass through a very fine sieve.

The moulds do not differ from those used for moulding by hand. According to the form of the object to be reproduced, they are in one or several pieces. After having put them together they are placed in such a way that the opening through which the body will be made to flow will be found at the upper part. The excess of body can be removed either through the same orifice, or (which is better for strong bodies) through a lower orifice, which is closed during the pouring by means of a plug. The slip is poured into the mould rather gently in order to avoid incorporating with it any air bubbles. It is allowed to remain for some minutes, then the body left is removed. The length of time depends on the plasticity of the body, and on the absorbing power of the plaster, that is to say,

on the thickness of the walls of the mould, and on their degree of humidity.

According to the dimensions of the piece, these walls should have from two to four inches, and it is usually necessary to have the mould dried in a drying stove after each operation. On rare occasions, for small pieces, they will be able to be used twice consecutively.

If the object to be made must have rather a large thickness, it is preferable to make the "pouring" in two or three times, allowing the body to harden a little between each operation. When the moulds have undercut, narrow parts, or ornamentations a little sunk, it is well to *paint* them before casting with the clear body by means of a brush, in order to prevent the air remaining imprisoned in it. It may happen that the absorbing action of the plaster may be too rapid, which would cause breaking in the pieces, but it is easy to remedy this by covering the inside of the mould with a very thin layer of an emulsion of hard soap in olive oil.

In other cases, for large pieces which must have strong thickness, the absorption of the plaster can, on the contrary, be hastened by placing the outside of the mould in a hermetically sealed box, in which the vacuum is made by means of a pneumatic machine. The same end can be arrived at by closing, on the contrary, the interior of the mould, and by putting it in communication with a reservoir of air under pressure.

Moulding by casting has great advantages in comparison with other processes. It simplifies the preparation of bodies and allows the making of very difficult pieces. Unfortunately, it only applies to certain bodies and necessitates a very large number of moulds, which rapidly wear away. It can also be used for the making of certain thin pieces which it would be difficult, if not impossible, to obtain by other processes.

### (*g*) *Finishing.*

113. *Finishing* consists of a series of manual operations, which are variable according to the form of the object made, but always having two aims:—

1. To correct the imperfections of making.

2. To unite the different pieces of an object, which have been obliged to be made separately.

The imperfections of making consist chiefly in the seams of the moulds, and in certain parts which had to be left solid, but which it is necessary to scoop out. When the pieces have been thrown, the finishing is generally done on the lathe. The body is first allowed to harden and then is proceeded with as has been described when dealing with turning. For objects obtained by other processes, finishing is done by means of hand tools, very diverse in form.

The only difficulty of this operation consists in effecting it at the time when the body has assumed the suitable consistency. The object must be hard enough not to lose its shape, and can yet be cut either by a knife or steel wire in such a way that shavings and not granulous pieces are produced. When this finishing must be done simultaneously on a large number of pieces, certain precautions must be taken so that their drying takes place equally. When necessary the latter is arrested by keeping the objects in a damp place.

The manual operations of finishing have different names, which vary a little in the various branches of the ceramic industry. They can be thus distinguished:—

*Scraping*, which consists in removing the seams from the moulds.

*Carving* (*undercutting*), in which those parts are removed which have been obliged to be left solid in order to work the delivery.

*Grooving* and *perforating*, the aim of which is to make in the body apertures or holes, which it would be too complicated or impossible to obtain directly in the making.

Finally, *repairing*, intended to correct by means of a small quantity of body and with scrapers the defects, such as bubbles, cavities and cracks, which have arisen during the making.

The reunion of the separate parts of a single object can be done by *sticking* or by *slipping*.

*Sticking* is employed to reunite the thick parts; an example of this has been given when dealing with throwing (Fig. 63). It must be done when the body is still sufficiently plastic to be

able to be made by hand, and yet having sufficient resistance not to lose its shape under a certain amount of pressure. The parts to be reunited are cut bevel edged, as is represented by Fig. 111. If the sticking must be done at a corner, a little of the body is added in the re-entering part, after having made it in the form of a small cylinder or point. The parts to be united are first moistened, then one hand is placed inside, the other outside, and pressure is exerted by endeavouring with the fingers to mix intimately the bodies of both parts. When the shape of the article does not allow of the hand being introduced on one side, it is replaced by a damp sponge fixed to the end of a stick. The sticking being finished, smoothing is done with a sponge, and equalisation with scrapers.

*Slipping* is employed for bodies which are but little plastic, and for fine objects, handles, spouts, feet or stands, ornaments,

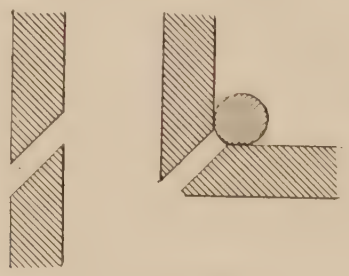

Fig. 111.—Sticking.

etc., which have been made by themselves and which would lose their shape by sticking. The body must in this case be more consistent. The objects to be united having been made and so adjusted that the surfaces to be slipped correspond exactly one with the other, these are rendered slightly rough by means of a small iron or a comb, they are covered with rather a liquid slip, and pressed strongly one against the other. At the end of a short time they can be released and the excess of body which forms a seam removed by means of a brush. Fig. 112 shows the surfaces of slipping (*mm*) of a vessel with a handle and a spout. *Sticking* is a very simple operation, but, in order that it may be successful, it is necessary that the objects to be joined, as well as the liquid body, should have the desired consistency. It is only experience which, in each case, enables the most favourable conditions to be determined.

The manual operations of slipping are known under the name of *handling* when they are applied to handles, spouts or stands, and by that of *sticking* (*sprigging*, *figuring*) when their aim is the placing of ornamentation.

### (*h*) *Slipping.*

**114. Slipping** is an operation the aim of which is to cover a body made by a layer of another body known by the name of a slip. In doing this, there can be three purposes :—

(1) To modify the colouring and the appearance of the first body.

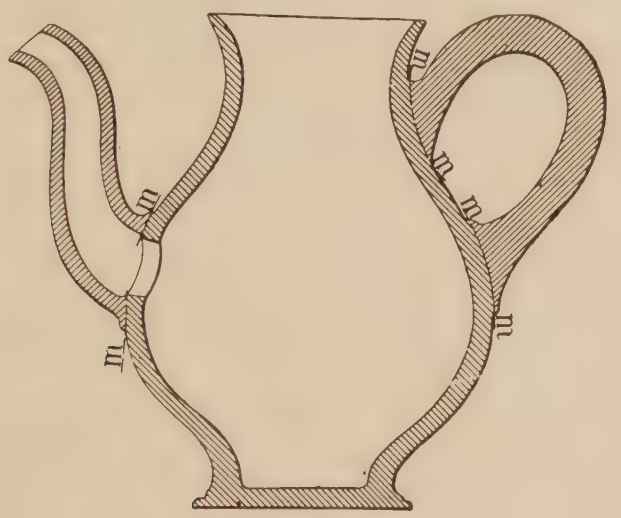

Fig. 112.—Handling.

(2) To give to the latter the properties suitable for enabling it to be covered with a given glaze.

(3) To obtain, by the use of bodies of various colours, decorative effects. The means employed for this purpose will be mentioned in the chapter relating to the decoration of pottery ware.

Considered merely in the light of fulfilling the first two aims, slipping is a very simple operation in itself. The only difficulty consists in finding a slip fulfilling the required conditions and having the same shrinkage in drying and in firing as the body made up. The desired composition can only be arrived at by trials in which is taken as the foundation the

slip which one has in view. Then there is mixed with it a plastic material, such as white clay, or a non-plastic material, such as fine sand, until the trial pieces obtained are without defects. If the body has more shrinkage than the slip the latter cracks, leaving in its place the bare body. If the contrary defect is produced the slip becomes detached and "breaks off in scales".

When the slip has the desired composition it is blunged in the state of a liquid body, as it has been stated when dealing with the preparation of bodies. It is sufficient to observe that the quantity of slip used, being always very slight, these are processes applicable to small productions which should be utilised.

The body made must on its part be hard enough to be able to be manipulated without danger of losing its shape, and, on the other hand, it must not be too dry, so as not to absorb the water of the slip, which would consequently become dry and would not adhere.

The placing on of the slip is done in different ways:—

By dipping the object in a vessel containing the liquid slip, either by immersing it entirely or by only dipping those parts which it is desired to slip.

By sprinkling, in pouring on the object the slip, the excess of which falls into a vessel placed below, a process employed when it is only desired to slip the exterior.

By filling the object with the liquid, and by emptying it shortly afterwards, a method utilised for slipping the inside of vessels.

Finally, by applying it with a brush.

It happens sometimes that the slip, formed of white clay and sand, is considerably more refractory than the body, and sticks to it badly after firing. This fault can be remedied by the addition of a certain proportion (from 1 to 10 per cent.) of alkalies, which considerably increases the fusibility and the adherence.

In certain cases it is necessary to give to the slip a greater thickness than that which it is possible to obtain by the means which have just been indicated. This circumstance arises particularly in the case of paving tiles, which are liable to diminish

in thickness by wearing, or when, in the making by mould, the pieces of pottery have projecting parts, for which it is desired to preserve a precise form. In the first case a thin slip would be quickly destroyed and would leave the body with its natural colouring; in the second case it fills the hollows, blunts the corners, and removes from the piece of pottery the special character which it is desired to give to it.

It is then necessary to have recourse to a process of slipping known by the rather unsuitable name of "incrustation," which consists in moulding simultaneously two bodies forming two layers placed above each other, the thinner, placed on the *apparent facing*, constituting the slip, and the thicker, inside, serving to give to the piece of pottery the thickness necessary for its solidity, representing the body properly so called. According to the processes of making employed, the incrustation can be done in different ways.

In making by hand with *plaster moulds* one begins by applying the layer of slip in the mould, in such a way that it well fills all the parts in relief; then the body is added, forcing it to stick as well as possible to the slip.

In making by *press*, a *rough outline* is first made by means of two layers of body placed above each other parallel; or, when the making is done with dry body, one begins by placing in the mould a certain quantity of powdered slip body, and the filling is accomplished by some pulverised body. In both cases the pressure determines the adhesion of the body and its slip.

In Chapter VIII., relating to decoration, will be found other indications on coloured slips.

# CHAPTER V.

## DRYING.

SUMMARY.—§ 1. *Drying of Bodies:* Theory of Drying—Influence of the Nature of the Body, of the Consistency and of the Method of Formation, of the Shape of the Objects, and of the Rapidity of the Drying.

§ 2. *Processes of Drying:* Drying by Evaporation—Aeration—Heating—Ventilation—Heated and Aerated Dryers—Dryers Heated and Ventilated with Fixed and with Movable Shelves—Drying by Absorption.

### § 1. DRYING OF BODIES.

**115. Theory of Drying.**—By the term *drying* is understood the operation by which the water of formation is removed from the bodies. The aim is to harden these sufficiently so that they can support the manipulation of the oven, and to make their firing more rapid and less eventual. It is only when the formation has been done in the dry body that the drying can sometimes be avoided and the ware placed in the oven immediately the bodies are made.

It has been seen in the preceding chapter that the drying could be done at least partially either by evaporation or by absorption in plaster moulds. But whatever the process may be, the modifications which are produced in bodies are the same and they can at first be studied independently of their cause.

If we examine what happens in the drying of any made body we see that it is naturally the surfaces which begin by losing a certain proportion of water. The latter is restored to them in part by the interior layers which are nearest to them, then this action is transmitted gradually till it reaches the centre of the mass. Then is produced a flowing of the water from the centre towards the surfaces, the more rapid, the more intense the elimination is, but the speed of it depends on the texture of the body.

This flowing takes place by capillarity. It continues with the same quickness so long as the drying action is not transmitted to

the centre of the ware; from that moment, the reservoir of humidity beginning to lower, the speed of the flowing diminishes, but it is not till after rather a long time that it ceases altogether, when the body is uniformly dry.

The elimination of the water takes place theoretically in two periods: in the first it is constant, proportionate to the duration of the drying; in the second it diminishes progressively until it ceases entirely.

On the other hand, so long as there remains in the body a sufficient quantity of water to allow the grains to become displaced, the latter collect together, filling up the spaces occasioned by the departure of the water which separated them. The result is a diminution in volume equal to the volume of water eliminated.

This action continues until there no longer remains sufficient water to allow the grains to move. From this moment the consequence of the elimination of the water is the production, in the interior of the body, of spaces equal to the volume of water which has been got rid of.

This second phase of the drying continues until the whole water of formation has been eliminated. If the drying has taken place equally throughout the whole mass, these two phases would be clearly distinct, but this condition being impossible to fulfil, the edges and the surfaces being necessarily dry before the centre, the drying is in reality subdivided into three phases:—

1. That in which the body diminishes in volume proportionally to the water eliminated.

2. That in which it begins to form spaces at the same time that the body continues to contract.

3. That in which the volume ceases to diminish, the spaces which are produced being proportional to the water eliminated.

These theoretical considerations can easily be confirmed by determining during the whole time of the drying of a body, and at fairly close intervals, its weight and its volume.

*Volume.*—The following table gives an example of trials of this kind, with a plastic clay made by hand in the form of cylinders of 1·575 in. diameter and 7·874 ins. long, the consistency being that of half-soft body:—

| Duration in Hours. | Weight of | | Shrinkage Lineal. | Volume of | | | Total. |
|---|---|---|---|---|---|---|---|
| | Clay. | Water. | | Clay. | Water. | Spaces. | |
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | |
| 2 | 75 | 25·0 | 2·1 | 55·1 | 44·9 | — | 100·0 |
| 12 | ,, | 21·5 | 3·7 | ,, | 38·7 | 0·0 | 93·8 |
| 24 | ,, | 18·0 | 5·1 | ,, | 32·4 | 1·8 | 89·3 |
| 36 | ,, | 14·5 | 6·5 | ,, | 26·1 | 3·3 | 84·5 |
| 48 | ,, | 11·2 | 7·6 | ,, | 20·2 | 6·4 | 81·7 |
| 60 | ,, | 8·0 | 8·0 | ,, | 14·4 | 9·4 | 78·9 |
| 72 | ,, | 5·6 | ,, | ,, | 10·1 | 12·7 | 77·9 |
| 84 | ,, | 3·8 | ,, | ,, | 6·8 | 16·0 | ,, |
| 96 | ,, | 2·5 | ,, | ,, | 4·5 | 18·3 | ,, |
| 108 | ,, | 1·7 | ,, | ,, | 3·1 | 19·7 | ,, |
| 120 | ,, | 1·1 | ,, | ,, | 2·0 | 20·8 | ,, |
| 132 | ,, | 0·7 | ,, | ,, | 1·3 | 21·5 | ,, |
| 144 | ,, | 0·3 | ,, | ,, | 0·5 | 22·3 | ,, |
| 156 | ,, | 0·0 | ,, | ,, | 0·0 | 22·8 | ,, |

It is seen that the trial piece, having in weight 75 per cent. of clay and 25 per cent. of water, and in volume 55·1 per cent. of clay and 44·9 per cent. of water, has experienced during a drying which has lasted 156 hours a lineal shrinkage of 8 per cent., its volume being reduced to 77·9, consisting of 55·2 per cent. of clay and of 28·8 per cent. of spaces.

These figures can be represented graphically (Fig. 113) by dividing an horizontal line proportionately to the number of hours, by raising perpendiculars for each dozen hours, on which are marked the volumes of clay, water, spaces, shrinkage, and connecting by continuous lines the points thus determined.

In the first stage of the drying, for about twelve hours, the initial volume of the trial piece, represented by AC, of which AB stands for the water and BC for the clay, is reduced to EG, of which EF stands for water, the shrinkage DE being equal to the volume of water eliminated.

In the second stage, from the twelfth to the sixty-ninth hour, the volume is reduced from EG to IL, the water passes from EF to JK, and the spaces, at first nothing, become equal to IJ.

Finally, in the third stage, from the sixty-ninth to the one hundred and fifty-sixth hour, the volume varies no longer, IL being equal to NP, and spaces are formed in the place of the water, which is eliminated more and more slowly.

The preceding table, as well as the graphic representation

(Fig. 113), only refer, let it be well understood, to conditions of experience, that is to say, to a given plastic clay, moulded by hand in the form of cylinders, dried slowly and regularly. It would suffice to make some modifications in any one to produce results more or less different, but the preceding example has been chosen as a type because it represents a frequent case in ceramics.

The theory of the drying of bodies being thus established, it remains to examine the action of the nature of the body, of the consistency and of the method of formation, of the shape of the objects, and finally, of the duration of the drying.

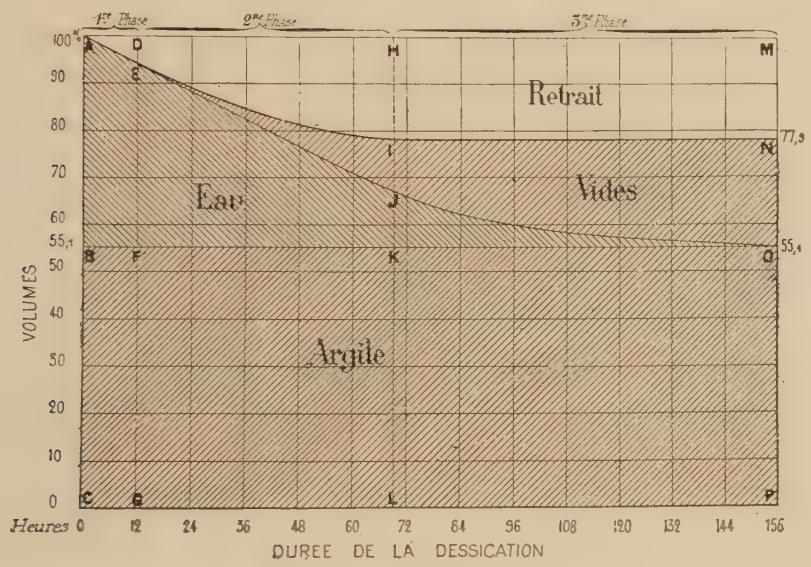


FIG. 113.—Diagram of Drying.

**116. Influence of the Nature of the Body.**—The following table shows the results of a great number of trials made with the most varied clays, by measuring the duration of the drying and the shrinkage of the spaces. This work has been done by giving to all bodies the consistency of half-soft body; cylinders have been made as previously (diameter 1·575 in., length 7·874 ins.), which have been dried simultaneously. Clays have been divided into four classes: kaolins (average of seven different tests), plastic clays (six tests), clays moderately plastic (fifteen tests), and open clays (nine tests):—

| | | | Duration of Drying. | Weight of the | | General Shrinkage. | Volumes of the | | | Total. | Affinity of the Spaces. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Clay. | Water. | | Clay. | Water. | Spaces. | | |
| Kaolins | | Plastic body | — | 72·7 | 27·3 | — | 52·6 | 47·4 | 0 | 100·0 | — |
| | | Dry body | 93 | ,, | 0 | 4·75 | ,, | 0 | 33·8 | 86·4 | 39·0 |
| Clays | Plastic | Plastic body | — | 72·9 | 27·1 | — | 52·8 | 47·2 | 0 | 100·0 | — |
| | | Dry body | 180 | ,, | 0 | 10·50 | ,, | 0 | 18·8 | 71·6 | 26·3 |
| | Non-plastic | Plastic body | — | 78·4 | 21·6 | — | 59·7 | 40·3 | 0 | 100·0 | — |
| | | Dry body | 144 | ,, | 0 | 8·30 | ,, | 0 | 17·3 | 77·0 | 22·5 |
| | Open | Plastic body | — | 83·2 | 16·8 | — | 66·5 | 33·5 | 0 | 100·0 | — |
| | | Dry body | 120 | ,, | 0 | 6·80 | ,, | 0 | 14·5 | 81·0 | 17·9 |

These experiments show the differences which exist from a ceramic point of view between kaolins and plastic clays. The

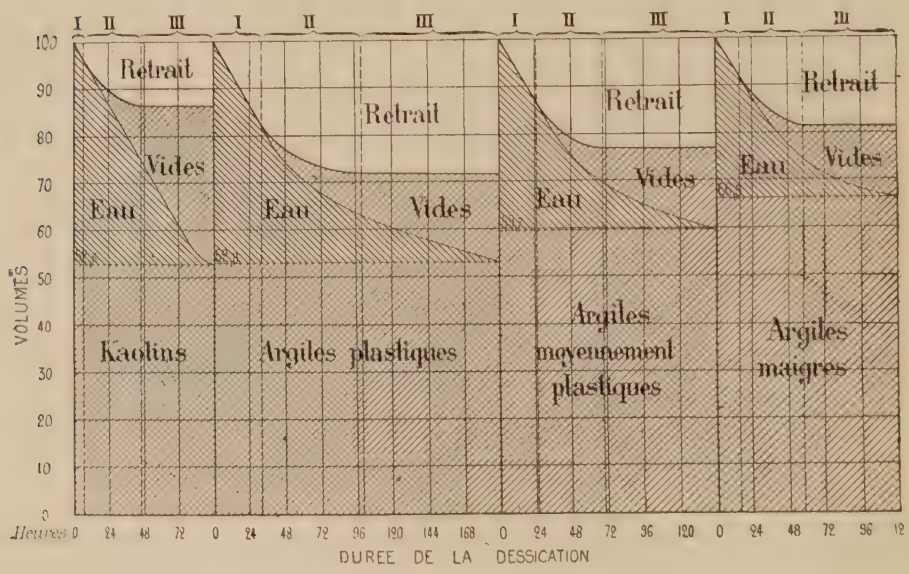


FIG. 114.—Diagram of the Drying of Different Bodies.

proportion of formation water is the same, but kaolins have a much prompter drying, a considerably slighter shrinkage, and, in consequence, a much larger proportion of spaces. On the other hand, clays, properly so called, present no other differences, except those which result from the variable proportion of the water of formation. The preceding results being average ones, certain clays can differ from them considerably, but in these cases an examination of their composition will reveal the cause of their divergencies. The preceding figures are represented graphically by Fig. 114.

Analogous results will be obtained with different plastic bodies.

Thus with reference to the duration of the drying, the shrinkage, the volume of the spaces, it is necessary at first to distinguish kaolinic bodies from clayey bodies. The first, all being equal, dry more rapidly, have less shrinkage and more spaces. This primary distinction being made, bodies only vary among themselves, from the point of view of the drying, by their contents of water of formation. The greater the latter is, the longer is the time taken in drying, the greater the shrinkage and the greater the amount of spaces. It is well to remember that the proportion of the water of formation only depends on the texture of the body, that is to say, on the fineness of its grains. As the grains of hydrosilicate of alumina are the most tenuous, these necessitate most water; then come those of carbonate of lime, those of silica (sand, quartz, silex, etc., finely pulverised), and, finally, those of coarse grained silica. Thus, given equality of plasticity, a pure clay opened with lime-stone will absorb considerably more water of formation than the same clay opened with silica.

117. **Influence of the Consistency.**—By modifying the consistency of a particular body, it is evident from the preceding observations that the duration of drying, the shrinkage, and the proportion of spaces will be made to vary at the same time. The firmer the body, the more rapid the drying, the greater the shrinkage and the slighter the spaces, but there is not an absolute ratio between these different quantities.

For example, if it is desired to make with a clayey body moderately plastic, containing 5 per cent. of hygrometric water, cylinders having a volume after drying of 100, it will be necessary in the humid state to give to these cylinders a volume of

| | | | | |
|---|---|---|---|---|
| 100 | for | 5 | per cent. | of water |
| 104 | ,, | 10 | ,, | ,, |
| 111 | ,, | 15 | ,, | ,, |
| 120 | ,, | 20 | ,, | ,, |
| 130 | ,, | 25 | ,, | ,, |
| 141 | ,, | 30 | ,, | ,, |

that is to say, the shrinkage in volume will be

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | per cent. | for | 5 | per cent. | of water, | or a lineal shrinkage of | 0 per cent. |
| 4 | ,, | | 10 | ,, | ,, | ,, | 1 ,, |
| 11 | ,, | | 15 | ,, | ,, | ,, | 4 ,, |
| 20 | ,, | | 20 | ,, | ,, | ,, | 7 ,, |
| 30 | ,, | | 25 | ,, | ,, | ,, | 11 ,, |
| 41 | ,, | | 30 | ,, | ,, | ,, | 16 ,, |

On the other hand, these 100 volumes of water will contain after drying

| | | | | | |
|---|---|---|---|---|---|
| 20 | per cent. | of spaces for | 5 | per cent. | of water |
| 21 | ,, | ,, | 10 | ,, | ,, |
| 22·5 | ,, | ,, | 15 | ,, | ,, |
| 24·5 | ,, | ,, | 20 | ,, | ,, |
| 27 | ,, | ,, | 25 | ,, | ,, |
| 30 | ,, | ,, | 30 | ,, | ,, |

In Fig. 115 these figures have been represented in graphic form, but it must be understood that they are only given as

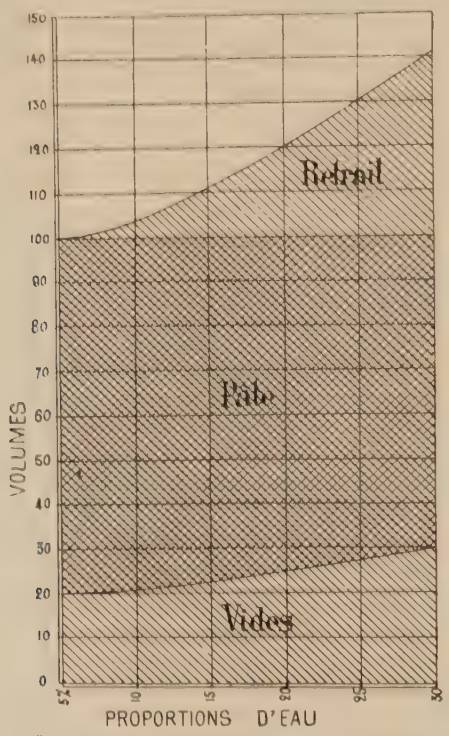


Fig. 115.—Influence of Consistency upon Shrinkage and Pores.

an example, for they depend on the nature of the body, on the method of formation, on the shape of the object, and, to a certain extent, on the rapidity of the drying. Their import must not, therefore, be considered absolute, but only as in keeping with the general law which they represent.

The duration of the drying is evidently thus influenced by the proportion of the water of formation. By making identical trial pieces, with bodies containing more or less water, by drying them together slowly, and by weighing them at regular intervals, it

can be proved that about three-quarters of the water is evaporated during a time which is perceptibly proportional to the contents of water, but that from this moment the drying becomes slower in proportion as the body becomes more consistent. By marking on an horizontal line the number of days taken in drying, on vertical lines the proportion of water remaining, and by joining by lines the points thus obtained, the progress of the drying can be represented graphically. Fig. 116 represents an attempt of this kind, made on the body previously spoken of. It is necessary here also only to consider this as a general indication.

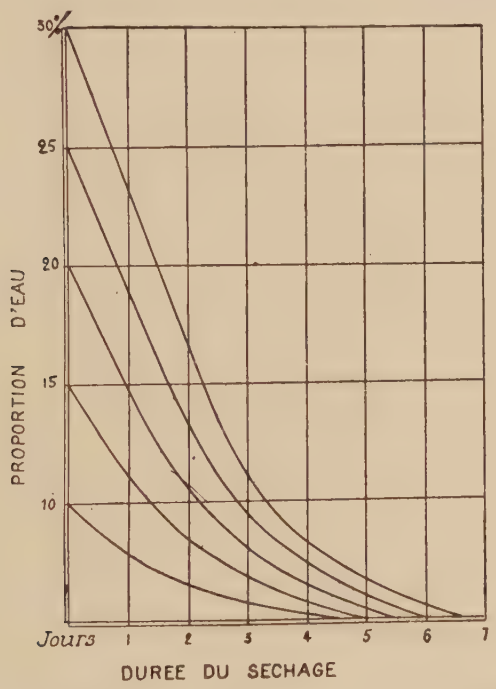


Fig. 116.—Influence of Consistency upon Duration of Drying.

Theoretically, the different methods of formation have no other influence on the drying except that which results from the variations in the consistency of bodies. Exception, however, must be made for certain defects of making, which are revealed at the time of drying, and which owe their origin to inequality of pressure. These are fairly frequent in moulding by hand and in throwing when the workman does not exercise a very regular pressure with his hands. They are also produced in the stretching, when it is difficult, as has been seen, to obtain a uniform

pressure in every section. Finally, in moulding by press, they can result through a defect in the mould. In all cases the parts most pressed dry most slowly; the result is inequality in shrinking, which causes deformation of the ware.

**118. Influence of the Shape of the Objects.**—The evaporation taking place on the surfaces, it is evident that the drying will be proportionately rapid, as these surfaces are large in reference to the volume. Thus a solid brick of 22 × 10·5 × 6 cm. has a surface of 852 square centimetres and a volume of 1,386 cubic centimetres, while a *hollow* brick of the same dimensions having 6 holes and sides 1 centimetre in thickness will have a surface of 1,779 square centimetres and a volume of 963 cubic centimetres. The proportion of the surface to the volume is, in the first case, 1 to 0·613, and in the second 1 to 1·870. The drying will, therefore, be three times more rapid in the case of the hollow brick than in that of the solid brick.

This proportionateness is obviously verified in practice for all wares having a uniform and relatively slight thickness, such as hollow bricks, quarries, tiles, thin pieces of pottery ware; but it is not the same for very thick articles, the flowing of the water by capillarity becoming more and more difficult in proportion as the thickness increases. For very large articles, such as refractory blocks, complete drying can only be obtained by employing powerful methods of drying.

In the drying of three spheres of different diameters, made by hand of rather an open body containing 20 per cent. of water, the following results have been obtained:—

| | | | |
|---|---|---|---|
| Diameter of spheres (in inches) . . | 2·047 | 3·937 | 7·56 |
| Proportion of surfaces . . . . | 1 | 3·65 | 13·4 |
| Proportion of volumes . . . . | 1 | 7 | 49 |
| Proportion of surfaces to volumes . | 1 | 1·91 | 3·66 |
| Half of water was evaporated at end of | 40 | 64 | 120 hours. |
| Drying was complete at end of . . | 100 | 250 | 600 ,, |

In a general way the principle can be enunciated that for thin ware the time of drying is, other things being equal, proportional to the thickness, or in the proportion of the surface to the volume.

For thick ware the drying follows at first an analogous way of proceeding, but it becomes considerably slower towards the end, and it is difficult to remove the last traces of humidity.

When the body is homogeneous, it is evident that the shrinkage should take place uniformly in all directions, all dimensions diminishing in the same proportion. However, in order that this principle may be applicable, it is necessary that the shrinkage may be able to take place equally, and not be impeded by even the shape of the object. The thin parts, corners and edges drying more rapidly, their shrinkage is hindered by the resistance of the thicker parts, which are still humid. Then, when the latter dry, they are in their turn restrained in their shrinkage by the thin parts, which are already rigid. The result is warping and tension, which cause ruptures.

Speaking generally, it is well to observe the following rules in the making of models:—

(1) Avoid too thick parts, by making, if necessary, some hollowings, so that every article may have, as far as possible, a uniform thickness. If it is impossible to fulfil this condition, at least avoid an abrupt passage from one thickness to another by making levellings.

(2) Avoid unsymmetrical shapes or parts which are too projecting. If these forms are enjoined, it is preferable to make the article in two or several pieces.

(3) Avoid objects of too large dimensions, especially when one of them is exaggerated in proportion to the others. It is better, as in the previous case, to make them in several pieces.

Even when applying these rules, it rarely happens, in the case of fairly large pieces or of more complicated shapes, that the shrinkage is absolutely uniform, and it is usually necessary, when the measurements must be accurate, to make retouches in the models, following the results observed in a first making.

**119. Influence of the Rapidity of the Drying.**—When the drying takes place slowly and regularly, the inequality between the humidity of the edges, the surfaces, and the narrow parts and that of the interior or thicker parts remains rather slight, so that the variations in shrinkage do not have troublesome consequences. It is no longer the same when the drying is very rapid. The antagonism between the parts already dry and those which are still humid can become rather great, not only sufficient to distort, but sometimes even to break the ware.

The rapidity with which the drying can take place depends on the shape of the article and on the texture of its body. With reference to the shape, we have just indicated the conditions which it must fulfil; as to the body, it must be neither too plastic nor too open. In the first case the greatness of the shrinkage causes distortion, and in the second the lack of cohesion causes ruptures.

For certain articles having narrow parts which dry too rapidly, the drying of these must be retarded by covering them with damp cloths, with fat texture, etc. Their formation also can only be accomplished when the drying is sufficiently advanced, so that no further shrinkage takes place.

In referring to the theory of drying, it is seen that, being great in the first period, it is reduced progressively in the second, to become obliterated in the third. It follows that the drying must take place with a certain amount of slowness in the beginning of the operation, but from the time when the body, having lost its plasticity, has no further shrinkage, the evaporation can, without fear, be strongly pressed. In practice this moment is easily recognised by the change of colour in the body, which becomes clearer.

The preceding considerations also enable one to take into account that the shrinkage must be slightly less when the drying is rapid than when it is slow. A direct trial has shown that, given two identical cylinders made with the same body, the one, dried in twenty-four hours, has had a shrinkage of 7·75 per cent., and the other, the drying of which has lasted fifteen days, has had 8·50 per cent. shrinkage.

## § 2. Processes of Drying.

**120. Drying by Evaporation.**—In order to dry a body by evaporation it must be placed in a relatively dry atmosphere which can provide it with a certain quantity of heat, and which can be renewed so that the water evaporated can be removed. First, it can be proposed to determine, independently of the process of drying employed, the volume V of air and the heat C necessary to evaporate 1 kilogramme of water contained in a body having $n$ per cent. of water of formation.

Let $\theta$ be the surrounding temperature.
" T " temperature of air entering into the dryer.
" $t$ " " " going out of the dryer.
" $p$ " weight of water vapour in grammes contained in one cubic metre of air entering.
" P " weight of water vapour in grammes contained in one cubic metre of air departing.
" $a$ " co-efficient of expansion of gas = 0·00366.
" 1·3kg " weight of a cubic metre of air at 0°.
" 0·237 " specific heat of the air.
" 0·200 " " of the body.

One cubic metre of air going out at $t°$, corresponding to

$$1 \times \frac{1 + \alpha T}{1 + \alpha t}$$

cubic metre of air entering at T°, the weight of water removed by this cubic metre will then be

$$P - p \times \frac{1 + \alpha T}{1 + \alpha t},$$

whence

$$V = \frac{1{,}000}{P - p\,\frac{1 + \alpha T}{1 + \alpha t}}. \qquad (a)$$

The heat given off by this air is equal to

$$V \times \frac{1{\cdot}3}{1 + \alpha t}\,(T - t) \times 0{\cdot}237,$$

or

$$\frac{0{\cdot}308\ V\ (T - t)}{1 + \alpha t}.$$

It is used to vaporise 1 kilogramme of water, requiring, according to Regnault,

$$606{\cdot}5 - 0{\cdot}695t \text{ calorics},$$

and to raise from $\theta$ to $t°$ the temperature of $n$ kilogrammes of body,

$$n \times 0{\cdot}2\,(t - \theta) \text{ calorics}.$$

From this we deduce this second equation:

$$\frac{0{\cdot}308\ V\ (T - t)}{1 + \alpha t} = 606{\cdot}5 - 0{\cdot}695t + 0{\cdot}2n\,(t - \theta). \qquad (b)$$

On the other hand, if it is granted that the air going out is saturated with humidity, $t$ and P are connected by a function given by the tables, indicating the tension of the water vapour

in the air at the different temperatures. On its part $p$ can be considered as a known quantity, that is, at the maximum, the weight of water vapour contained in one cubic metre of air at $\theta°$. There remain therefore, in reality, three unknowns: V, T and $t$, connected by two equations ($a$) and ($b$), which, in leaving the problem indeterminate (=unsolved), allows the choice of the most suitable values for T and $t$.

As to the quantity of heat expended, it is equal to the number of calorics necessary to raise the temperature of the volume V of air from $\theta$ to T; it is therefore given by the formula

$$C = V \times \frac{1{\cdot}3}{1 + \alpha t} \times 0{\cdot}237 \times (T - \theta),$$

or

$$C = \frac{0{\cdot}308V\ (T - \theta)}{1 + \alpha t}. \qquad (c)$$

By replacing V by its value deduced from the formula ($a$) we have

$$C = \frac{308\ (T - \theta)}{P\,(1 + \alpha t) - p\,(1 + \alpha T)}. \qquad (d)$$

These formulas are not very easy of application; it is better to reserve them for more complete studies, and in practice to take the following table as base:—

| Temperature. | Maximum tension of Water Vapour. | Maximum weight of Vapour contained in 1 m³ of air. | Heat absorbed by 1 m³ of dry air, the temperature of which is raised by 1°. | Heat absorbed by the volatilisation of 1 kg. of Water. | Water evaporated by 1 m³ of dry air, the temperature of which is lowered by 1°. |
|---|---|---|---|---|---|
| Degrees. | Mm. of Mercury. | Grammes. P | Calorics. $c$ | Calorics. | Grammes. E |
| 0 | 4·5 | 4·8 | — | 607·0 | — |
| 5 | 6·5 | 6·7 | 0·303 | 608·5 | 0·498 |
| 10 | 9·1 | 9·3 | 0·297 | 610·0 | 0·487 |
| 15 | 12·7 | 12·7 | 0·292 | 611·5 | 0·477 |
| 20 | 17·4 | 17·1 | 0·287 | 613·0 | 0·468 |
| 25 | 23·6 | 22·8 | 0·282 | 614·5 | 0·459 |
| 30 | 31·6 | 30·1 | 0·278 | 616·0 | 0·451 |
| 40 | 55·0 | 50·9 | 0·269 | 619·0 | 0·434 |
| 50 | 92·0 | 82·3 | 0·261 | 622·0 | 0·418 |
| 60 | 148·5 | 129·1 | 0·253 | 625·0 | 0·404 |
| 70 | 232·6 | 195·3 | 0·245 | 628·0 | 0·391 |
| 80 | 353·9 | 290·2 | 0·238 | 631·0 | 0·378 |
| 90 | 527·0 | 412·7 | 0·231 | 634·0 | 0·365 |
| 100 | 760·0 | 589·5 | 0·226 | 637·0 | 0·355 |

E being the weight in grammes of the water evaporated by

1 cubic metre of air, the temperature of which is lowered by 1°, the volume V is easily found by the formula

$$V = \frac{1{,}000}{E\,(T - t)}, \qquad \text{(I.)}$$

in which we take for E the value corresponding to the temperature $\frac{T+t}{2}$. It must be observed that $p + E\,(T - t)$, that is to say, the weight of water removed by 1 cubic metre, must be lower than, or at most equal to, the value of P corresponding to the temperature $t$.

Either

$$p + E\,(T - t) \lesseqgtr P,$$

or

$$E\,(T - t) \lesseqgtr P - p. \qquad \text{(II.)}$$

On the other hand, C being the heat furnished by 1 cubic metre of air, the temperature of which is raised by 1°, the heat employed C is given by

$$C = V\,(T - \theta)\,c,$$

in which we take for $c$ the value corresponding to the temperature $\frac{T+\theta}{2}$, or, by substituting for V its value obtained from formula I.,

$$C = \frac{1{,}000\,(T - \theta)\,c}{E\,(T - t)}. \qquad \text{(III.)}$$

In the following articles will be found examples of the application of these formulas.

In order to take account of the working of an existing dryer, it is necessary to measure the temperatures $\theta$, T, $t$, and the contents of water vapour $p$ and P. But these determinations, which it is, moreover, sometimes impossible to make, do not give any information on the variations which can be produced in the interior of the dryer. For this purpose one can often make use, with advantage, of a small apparatus shown in Fig. 117, and called an evaporometer. It consists of a glass tube graduated with centimetres, closed at its upper part, which is terminated by a ring, by which it can be suspended, and the lower part can be closed by a sheet of blotting-paper, having a given surface and held by means of a small spring. The tube is filled with water, it is closed with the blotting-paper, and

the apparatus is hung up in the dryer. At the end of a certain time the volume of the water evaporated is read on the graduation, which has no signification of absolute value, but which, by comparison with the figures given by other apparatus, is proportional to the intensity of the drying in the part of the dryer in which it has been placed.

Fig. 117.—Evaporometer.

These evaporometers can be rendered more exact by reducing the section of the measuring tube, and by increasing the surface of evaporation. This slight complication does not apparently have practical utility.

The theoretical principles of drying by evaporation being thus established, we obtain successively natural drying, or drying by aeration, the processes of heating and of ventilation of the dryers, and the principal systems of artificial dryers.

**121. Aeration.**—We designate under the term of aeration the drying of bodies in the open air. The heat necessary for the evaporation is furnished by the atmosphere; the renewal of the air is caused by the action of the wind and by the difference of weight which there is between the exterior air and the thicker air of the dryer.

In aeration there can evidently be no drying except when the atmosphere is not itself saturated with water vapour, which is frequently the case in time of rain or fog. In order that the drying may be brisk, the temperature must not be too low, nor the velocity of the wind too slight. However, a dry or even fresh wind is better than a heavy heat, without displacement of the air.

It is well, in the setting up of dryers by aeration, to avoid low, sheltered places, and to choose well-aired pieces of land, by placing dryers there as high as possible above the surface of the ground. The drying is doubly as rapid at a height of 3 ft. 3 ins. than on the ground itself, and trebly so at a height of 6 ft. 6 ins. It is also necessary to avoid the pressing too closely together, and the placing one too closely to the other. They should be arranged in such a way as to be easily traversed by

the wind, and to present their largest surface in the direction of the most frequent dry winds. It is also necessary to protect the ware against the rain, by considering that the latter can be often driven sideways by the wind, and by making all arrangements to ensure a rapid flowing of the waters.

If such are the general conditions for obtaining a good aeration, it must not be neglected to take precautions to avoid it becoming too brisk. It is well for this purpose to arrange movable screens, which diminish the swiftness of the too violent winds, and prevent the rays of the sun from striking directly on the ware.

Except for the manufacture of certain common bricks, which

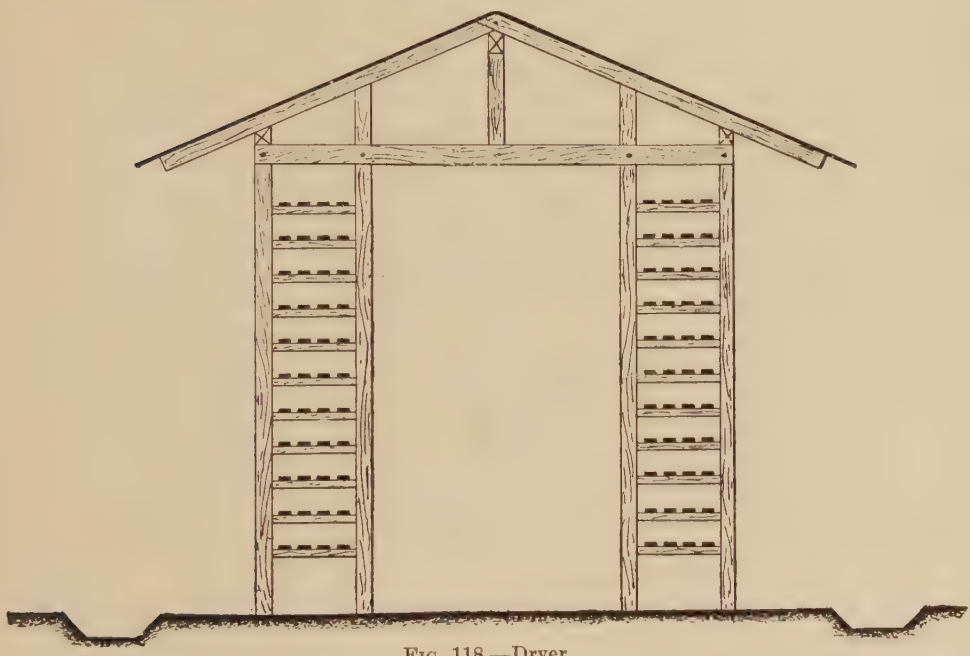

Fig. 118.—Dryer.

are sometimes simply piled one on the top of the other, the ware is generally arranged on isolated wooden stages (Fig. 118), or grouped together in the same structure (Fig. 119). The pieces of ware are sometimes placed direct on these shelves, but most often each of them is supported by a plank or wooden frame, the form and dimensions of which depend on those of the objects.

In the climates of Western Europe aeration can only take place during five to eight months of the year. The drying must

then be interrupted during the cold and humid months. If the exterior temperature falls to 2° or 3° below zero, the water contained in the ware freezes, and the increase in volume of the ice disaggregates the body, which falls to pieces or contracts bubbles at the time of thaw. This destructive action of the frost is not produced on bodies which do not contain more than their hygrometric water.

As a matter of curiosity, one can determine the volume of water necessary to evaporate by aeration one kilogramme (2·2046 lb.) of

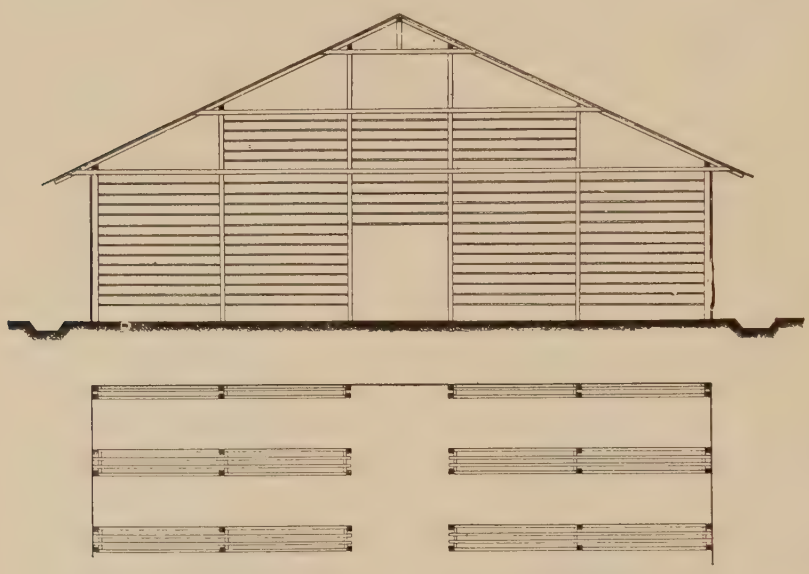

Fig. 119.—Dryer.

water. As the temperature of the air entering into the dryers is that of the atmosphere, $T = \theta$, and formula I. becomes

$$V = \frac{E\,(\theta - t)}{1{,}000},$$

with condition II.,

$$E\,(\theta - t) \geqq P - p.$$

In damp climates the water vapour contained in the air is on an average $\frac{2}{3}$ of the maximum weight which it can contain. It is reduced to the half in dry climates. On the other hand, the average temperature during the seasons in which aeration is possible varies from 8° to 25°. All these figures have reference to European

meteorological conditions; it follows that a fall of temperature in the dryers can never be more than to $\frac{1}{5}\,\theta$, that is to say that

$$\theta - t = \frac{1}{5}\,\theta.$$

It follows that for an outside temperature of 10° we have

$$V = \frac{1{,}000}{0{\cdot}490 \times \frac{10}{5}} = \text{about 1,000 cubic metres,}$$

and for a temperature of 25°

$$V = \frac{1{,}000}{0{\cdot}460 \times \frac{25}{5}} = \text{about 430 cubic metres.}$$

These figures may appear considerable, but it must be noted that a wind scarcely sensible of 6 ft. $6\frac{3}{4}$ in. a second is sufficient to send through an aperture of ·155 square inch a volume of 94·17 cubic yards per hour.

In spite of its great inconveniences aeration is very much used for the drying of heavy ceramic wares containing a large quantity of water—solid bricks, bodies going out of filter presses, etc.—because, beyond the expenses of installation, the only cost is for the necessary manual work of removing the ware and placing it on the shelves.

**122. Heating.**—It has been seen that the heat expended to evaporate one kilogramme (2·2046 lb.) of water is given in formula III.

$$c = \frac{1{,}000\,(T - \theta)\,c}{E\,(T - t)}.$$

By granting that the outside temperature $\theta = 0$, this relation is reduced to

$$c = \frac{1{,}000\,Tc}{E\,(T - t)}.$$

This heat is least when E (T—$t$) is greatest, that is to say when this production is equal to P—$p$ (formula II.). In other words, the heat expended for the evaporation is least when the air goes out saturated with water vapour.

In admitting this case, and by giving different values to T, the heat expended at the various temperatures can be determined. The table (page 250) only giving the values of $c$ and of E at every 5°, the intermediate numbers are determined by calculation of their proportions. Here are the results of this calculation :—

| Temperature of the air entering into the Dryer. | Minimum temperature of the air going out from the Dryer. | Number of Calories expended to evaporate 1 kg. of water (2·2046 lb.). |
|---|---|---|
| Degrees. | Degrees. | |
| 20 | 11 | 1,360 |
| 40 | 18 | 1,120 |
| 60 | 24 | 1,030 |
| 80 | 28 | 960 |
| 100 | 31 | 930 |

These figures are the minimum, and they must be increased from 50 to 100 per cent., according to the installations, in order to have the real expenditure in calories. They show that it is desirable to heat as much as possible the air entering into a dryer, on condition, let it be well understood, that it always goes out saturated with water vapour.

It is rare that a dryer can be heated directly with gas proceeding from a hearth. Not only would the working of the latter be difficult to obtain, but the gas of the combustion leaves on the ware deposits of carbon substances and occasions condensation of sulphurous vapours, which are always injurious.

The heating of the air can be done in two ways: either the heat is produced in the interior itself of the dryer, or the air enters into it, having been previously heated. In both cases it is sought to utilise as much as possible the heat which has been lost from the *stoves*, or from the waste steam of the machines without condensation.

**123. Ventilation.**—In many cases ventilation is produced by simple aeration, that is to say that the air enters and departs from the dryers heated by openings more or less regulated, or sometimes simply by fissures of the partitions and of the roofing. This system is only permissible when there is a great excess of lost heat, or when the drying is done in places of habitation. However, it is nearly always usual to have recourse to a special process of ventilation, that is to say, to *flues* or to mechanical ventilation.

In *flues* the air must depart at a higher temperature than that of the exterior. Its velocity is given by the following formula (page 347):—

$$v = \frac{\sqrt{2ga\mathrm{H}\,(t - \theta)\,(1 - a)}}{1 + a\theta},$$

in which

$$g = 9{\cdot}8088 \qquad a = 0{\cdot}00366.$$

H is the height of the chimney: $t$ the temperature of the air going out; $\theta$ that of the outside air; $a$ the relation of the resistance opposed to the current of air by all the obstacles which it meets on its way to the base of the chimney. By making S the section of the chimney, the volume of the air departing is—

$$V = S \times v.$$

If the way traversed by the air is not long, if the resistance is slight and the section S large enough, a good ventilation can be

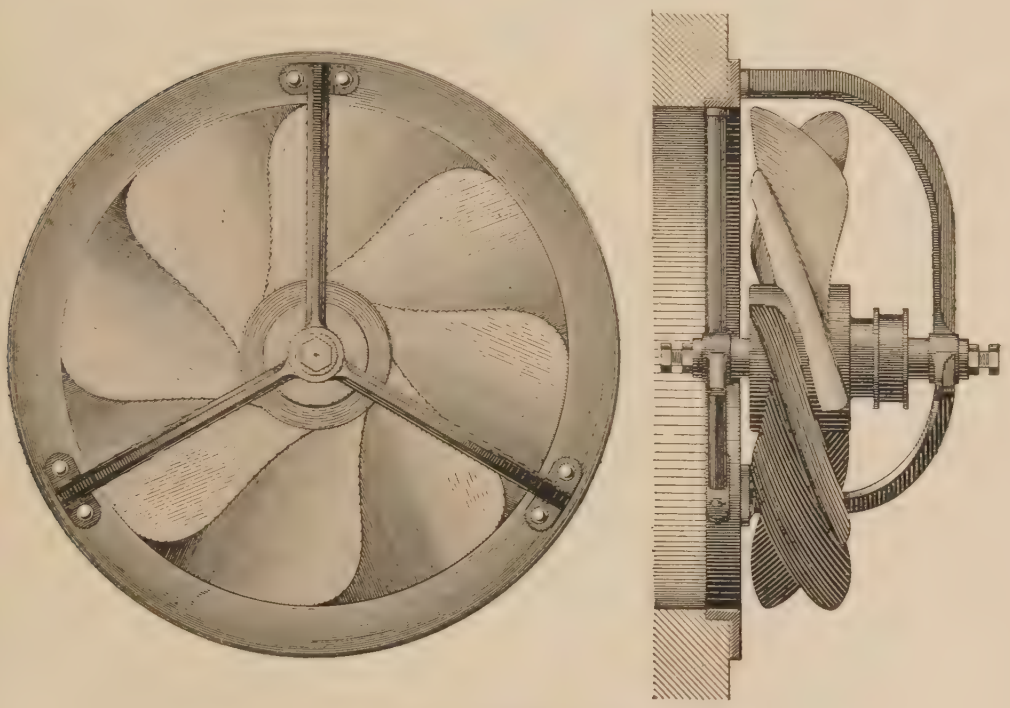

FIG. 120.—Ventilating Fan.

obtained with chimneys from 25 ft. to 50 ft. high, for differences of temperatures $(t - \theta)$ of only 3° to 4°. As the temperature $t$ is never very high, these chimneys are generally made of joined planks or covered with tarred paper.

Mechanical ventilators must be used whenever a current of air meets with a rather great resistance on its course. If they have the disadvantage of necessitating a motive force, they have, on the other hand, the advantage of ensuring a powerful action which can be regulated at will, independent of the interior temperature and of the

exterior; their use also is becoming more and more frequent. They are all based on the same principle, only the shape of the fans varies according to the constructors.

Figure 120 shows the arrangement generally adopted. A pulley causes a beam to turn, which is upheld by two ledges supporting the ventilator with fans, properly so called. The structure is fixed in any position, vertical, horizontal or inclined, against the wall or a partition having a circular aperture, the diameter of which is equal to that of the ventilator. The latter takes in the air and compresses it by the aperture.

Here are some indications on those apparatus:—

| Diameter. | Number of Revolutions. | Volume of Air given out per Minute. | Motor Force employed. |
|---|---|---|---|
| Inches. | | Cubic Feet. | Horse Power. |
| 14·548 | 1,200 | 3,533 | ½ |
| 21·822 | 1,000 | 7,067 | ¾ |
| 27·278 | 850 | 14,134 | 1 |
| 32·753 | 750 | 21,201 | 1½ |
| 38·188 | 700 | 28,268 | 2 |
| 43·644 | 600 | 35,335 | 3 |

The ventilators most used have from 21·822 in. to 38·188 in. diameter; the depression varies from ·03957 in. to ·3937 in. of water, according to the velocity. The systems now most known are those of Blackman, Scott, Desgoffes and Georges.

The transmission of force is often rather difficult to establish. It is generally done by thick cords by means of an intermediary transmission. Sometimes it is found advantageous to employ a small electric motor.

**124. Heated and Aerated Dryers.** — Artificial dryers can be divided into three classes:—

1. Dryers heated and aerated.
2. Dryers heated and ventilated with fixed shelves.
3. Dryers Heated and ventilated with movable platforms.

In heated and aerated dryers the lost heat is made use of, or special processes of heating are employed, often only working during the bad season, but there is not any ventilation properly so called, the renewing of the air being made by aeration. The heat is never very high, also the workman can make it circulate there constantly. They are often placed near or even in the place intended for the

manufacture. The ware is placed, as in the case of aeration, on fixed ledges.

The arrangements adopted are very variable according to the source of the heat utilised, the processes of manufacture and the local circumstances. They can, however, be divided into three groups :—

(*a*) *Dryers placed by the side of or above the furnaces, utilising their lost heat.*—This arrangement is very much used in brickworks, tile factories, drain pipe factories, quarry factories, etc. Fig. 121 shows one of these applications. The oven is placed in the centre of the structure, of which the upper ledges are occupied

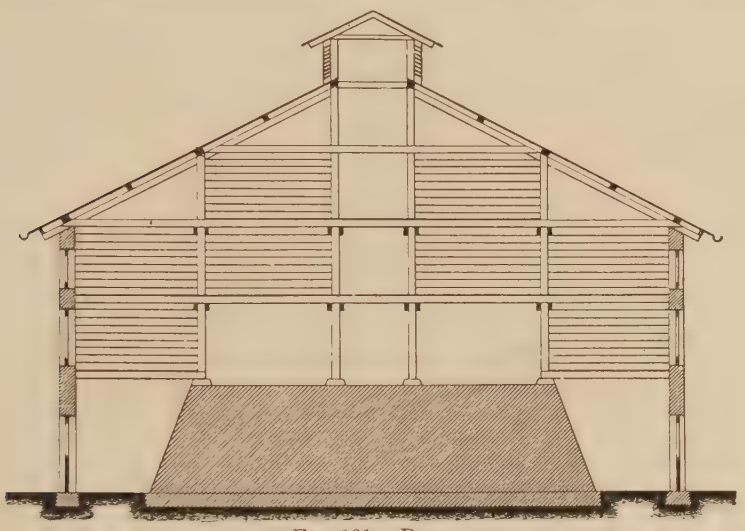

Fig. 121.—Dryer.

by the dryers. The aeration takes place by means of windows and of the roof lantern. The heat from the oven is sufficient to raise the interior temperature of the structure by some degrees, and to shelter the ware from frost. The drying is very economical, but it is often rather irregular and greatly influenced by the outside atmospheric conditions.

(*b*) *Dryers heated by circulation of hot air, hot water or vapour.*—This arrangement is frequently used in potteries, faience factories, porcelain works, where the rough action of the heat set free from the ovens is to be feared. The shelves are generally placed in the places used for the making, and the canalisation is near the wooden floor. Aeration takes place equally by the

windows or by special openings. The heating varies according to the exterior temperature.

This arrangement has the advantage of placing the dryers near the workmen employed in the making, and of enabling them to supervise the drying. On the other hand, it is not economical, and compels them to remain in a warm, damp atmosphere to the injury of their health.

(*c*) *Dryers heated by flues placed above the floor, the place being able to serve either for the making or being exclusively reserved for drying.*—This arrangement is seen chiefly in manufactories for refractory ware, where one has often to manufacture pieces, the dimensions of which are too large to allow them to be moved in a damp state. The heating is effected sometimes by causing pipes to circulate under the ground, connecting the

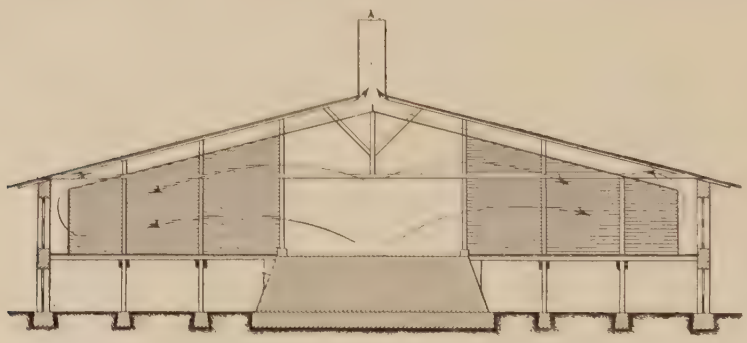

Fig. 122.—Dryer.

ovens with the chimney; also special fireplaces are frequently employed, the gas from the combustion of which circulates in the channels in a zigzag way before reaching a flue. These channels are covered with terra cotta slabs or plates of sheet-iron, the thickness of which diminishes in proportion to the distance from the fireplace. This arrangement can only be recommended for the special case which has just been mentioned.

125. **Dryers Heated and Ventilated with Fixed Shelves.**—In dryers heated and ventilated with fixed stages, the renewing of the air is produced by means of flues or ventilators, the pieces of ware remaining throughout the time of drying in isolated chambers. The arrangements most generally employed can also be divided into three groups:—

(*a*) *Dryers placed by the side of or above the kilns, in*

*order to use their waste heat.*—This arrangement has sometimes been made use of in brickworks or tile works possessing a continuous fire kiln, after the plan of Hoffmann. There are three different systems which will be described in Chapter IX.: Fig. 122 shows an arrangement, given only as an example. The kiln is covered by a large building in transverse section. It is divided in its length into six, seven or eight chambers, from

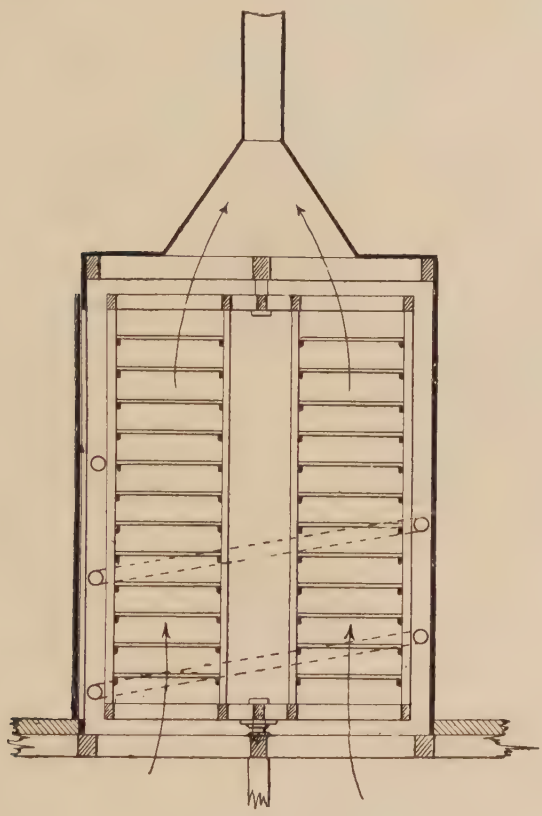

FIG. 123.—Dryer.

13 ft. to 20 ft. wide. The air heated from above the oven traverses these chambers before passing under the roof of roofing-felt, and escapes by the central flues. In the special case in which these dryers are applied, the heat furnished by the kiln is usually insufficient, and this arrangement does not show any advantages over that represented in Fig. 121.

(*b*) *Dryers formed by chambers entirely isolated, and heated by means of a lower system of pipes, the aeration taking place*

*by means of a flue at the upper part.*—This arrangement is frequently employed in faience manufactories. The heating of these chambers can be constant, the placing of the damp ware on the shelves and the removal of the dry ware being done by workmen who enter the dryer. As this work is very difficult, it is often preferred to arrange several drying stoves, and to make them work in an intermittent manner, by stopping the heating and the ventilation when the ware is dry in one of them, and by commencing working again when it has been

FIG. 124.—Revolving Dryer.

emptied and filled afresh. Circular stagings are also made use of, which can turn round a vertical axis, being enclosed in a framework likewise circular, provided with one or several sliding doors (Fig. 123) enabling the damp pieces of ware to be placed and the dry pieces removed. The heating is done by means of steam piping arranged in spiral fashion, and the ventilation takes place by the entry of air at the lower part and a flue at the upper part. The action is continuous. For larger outputs several of these frameworks can be grouped together, turning round the same vertical axis. Fig. 124 shows in horizontal section an

arrangement of this kind. The heating and the ventilation are worked in the same way as in the preceding arrangement.

It must be noted that if, in these last drying stoves, the shelves can be worked by a rotatory movement, the aim of this is only to facilitate the manual work, and that it has no influence on the drying, properly speaking, as is the case with the drying stoves in the following article (126).

(*c*) *Drying stoves having the form of tunnels, the wares*

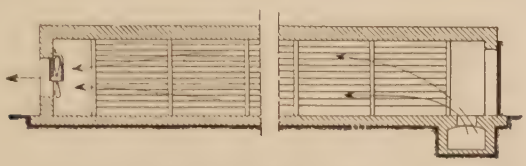

FIG. 125.—Dryer (Plan).

*being placed on fixed shelves, or the latter being mounted on waggons;* but in this latter case they are not displaced during the drying, this arrangement only having the purpose of reducing manual labour. The heating is done by means of hot currents of air taken in by the flues or ventilators.

Drying stoves of this kind are very diverse in arrangement. The most simple is that shown in Fig. 125. In a series of parallel tunnels are placed shelves. The hot air proceeding from the heat given off by a heater is distributed to one of the

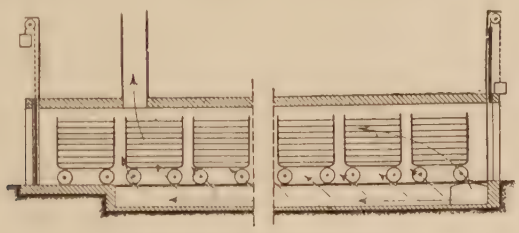

FIG. 126.—Funnel Dryer.

extremities of each tunnel by a subterranean longitudinal channel, and it departs charged with humidity at the other end, drawn out by a ventilator. This kind of drying stove has a great drawback. It is indeed easy to take into account that if, at the beginning of the drying, the hot air evaporates the water from the ware placed at the entry of the tunnel, it cools at the other end, leaving the steam to become condensed on the pieces of ware, which can cause softening and distortion.

In the arrangements shown in Fig. 126 this drawback is partially avoided. The drying stoves are, as in the preceding case, placed by the side of each other, but the introduction of hot air takes place uniformly throughout the length of the floor. Waste heat can be utilised, but more generally stoves are arranged on the ground, which heat the air sent into the drying-room. Steam piping is also made use of, being placed on the ground or inside the drying-room itself.

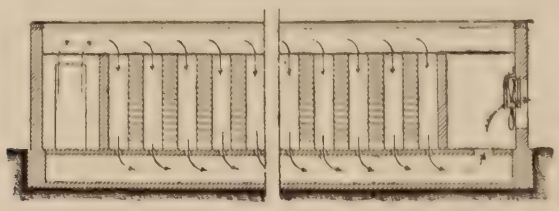

Fig. 127.—Dryer.

The subdivision of the drying can be pushed further still, as indicated in Fig. 127. In this arrangement, proposed by M. Hotop, the shelves are fixed and placed in a long gallery. The hot air brought by an upper pipe is distributed through the apertures regulated between the ranges of shelves. It departs by a series of similar openings pierced in the floor and communicating with a pipe of evacuation. The movement of the air can also take place

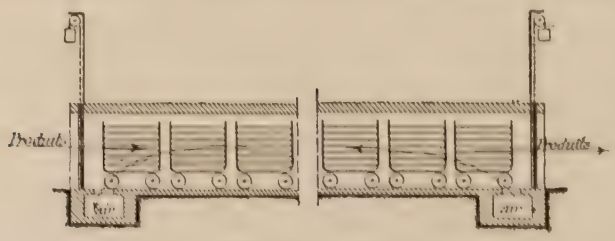


Fig. 128.—Dryer.

in a contrary direction. All these drying stoves have to be regulated with care, if it is desired to avoid too speedy a drying at the beginning, and at the end a useless expenditure of heat by heating the ware already dry.

**126. Dryers Heated and Ventilated with Movable Shelves.**—These drying stoves have a continuous action. The pieces of ware are placed on shelves mounted on waggons, which are methodically displaced in a tunnel, the damp pieces of ware being introduced at

one end and the dry pieces of ware removed at the other. The arrangements employed for this purpose are of three kinds.

(*a*) *Drying stoves in which the air moves in a contrary direction to the ware.*—As shown in Fig. 128, the hot air is introduced at one end of a tunnel and is removed at the other by means of a ventilator. When the last waggon on the side of the entry of the air is dry, it is drawn back and replaced by another, laden with damp pieces of ware, at the opposite end. The movement of the waggons takes place by means of winders or cranes. This can be facilitated by giving an inclination to the tunnel, so as to make it descend on an inclined plane.

After what has been said in article 122 we see that it is desirable to heat the air as much as possible. If the latter penetrates into the drying stove at 140° F. it goes out from it saturated with

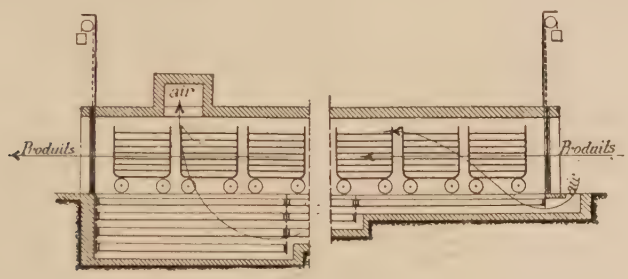


FIG. 129.—Dryers.

water vapour at 58° F., with an expenditure of 1,030 calorics per kilogramme of water evaporated. When the air is at 212° F. the temperature of the going out is 88° F. and the expenditure is 930 calorics. It is necessary to add to these figures the heat removed by the body, as, given a body with 20 per cent. of water of formation, 60 calorics in the first case and 100 in the second, the exterior temperature being supposed equal to 32° F. Finally it is desirable to increase the expenditure from 25 per cent. to 50 per cent. in order to take into account the various losses of heat, so that in the most favourable case the heat necessary to evaporate 1 kilogramme of water will be :—

$$(930 + 100) \times 1{\cdot}25, \text{ or about } 1{,}300 \text{ calorics.}$$

(*b*) *Drying stoves in which the air is displaced in the same direction as the ware by heating progressively*—Fig. 129 shows

the principle of the arrangement. The exterior air enters at one end of the tunnel. It is heated by steam piping and by heaters in such a way that its temperature increases in proportion as it advances in the tunnel and as it becomes charged with water vapour, going out at the other end with the maximum of heat. The working of the waggons is done as in the preceding arrangement. The formulæ given previously (article 120) do not apply in this case, and it seems impossible to establish the theory of this drying stove without the intervention of the working of a higher degree, which connects the tension of water vapour with the temperature. It is therefore better to be content with the working out of an example Let it be granted that this drying stove is divided vertically into ten parts, the air only going out from one of these parts to enter into the next completely saturated with water vapour. As the evaporation must be regular in all the length of the drying stove, each part must evaporate one-tenth of the water, or 100 grammes for an evaporation of 1 kilogramme.

Let us suppose 1 cubic metre of air entering at 0° C. saturated, that is to say, containing 4·8 gr. of vapour. By heating it to 20° C. it expands and gives

$$1 + (0{\cdot}00366 \times 20) = 1{\cdot}073^{m3},$$

which contains

$$1{\cdot}073 \times 17{\cdot}1 = 18{\cdot}3 \text{ grammes}$$

of vapour. The evaporation produced by this cubic metre in the first part has therefore been

$$18{\cdot}4 - 4{\cdot}8 = 13{\cdot}6 \text{ grammes.}$$

Each of the given parts being obliged to evaporate the same quantity of water, the total evaporation produced by this cubic metre at 0° C, will be 136 grammes. The departing air must have, being saturated, a temperature of 58° C., or 60° C. to simplify the calculation. At this temperature, in fact, 1 cubic metre of air at 0° can contain

$$[1 + (0{\cdot}00366 \times 60)]\, 129{\cdot}1 = 157 \text{ grammes.}$$

It will take, therefore, in order to evaporate 1 kilogramme of water,

$$\frac{1{,}000}{136} \quad 7{\cdot}35^{m3}.$$

The heat expended will be :—

| | |
|---|---|
| For the vapour . . . . | $606{\cdot}5 - 0{\cdot}695 = 605{\cdot}80$ |
| ,, air . . | $1{\cdot}3 \times 0{\cdot}237 \times 60 \times 7{\cdot}35 = 135{\cdot}72$ |
| ,, body . . . . | $5 \times 0{\cdot}2 \times 60 = 60$ |
| | 801·52 |

a total which, increased as previously by 25 per cent., gives an expenditure of about 1,000 calorics.

In certain cases this expenditure can be reduced by employing the air departing to heat that which has just entered. If, as has just been seen, the air goes out at 60° C., its temperature can, by means of calorifers, be reduced to 30° C. The heat which can thus be recuperated can be calculated as follows :—

Heat given by air :

$$1{\cdot}3 \times 0{\cdot}237 \times 30 \times 7{\cdot}35 = 66{\cdot}86 \text{ calorics}$$

by the vapour :—

$$[606{\cdot}5 - (0{\cdot}695 \times 60)]\ 129{\cdot}1$$
$$- [606{\cdot}5 - (0{\cdot}695 \times 30)]\ 30{\cdot}1 = 55{\cdot}68$$
$$55{\cdot}68 \times 7{\cdot}35 = 409{\cdot}24$$
$$\text{or, altogether, } 477{\cdot}10 \text{ calorics}$$

In the example chosen the recuperation would then allow, in order to evaporate 1 kilogramme of water, of reducing the expenditure to 823 calorics.

If we compare the two kinds of drying stoves with movable shelves which have just been described, we see that the first are of a lower thermic capability, and also that they must be used only for utilising waste heat. The second, of much greater use, do not lend themselves well to this utilisation, but it is preferable to use them each time that the heat must be provided by a special heating.

In these drying stoves the chief difficulty consists in obtaining throughout the section a uniform atmosphere. If mechanical means are not employed to force the circulation of the air, the upper part of the drying stove is necessarily filled with a warm and damp atmosphere. The system proposed by M. Moeller, shown in Fig. 130, completely obviates this difficulty.

In a tunnel, *A*, circulate several ranges of waggons laden with ware to be dried, which are introduced by the door, *B*, and go out from *C*. The outside air penetrates by the door, *B*, which is partially opened, and is drawn in by a first ventilator, $D_1$, $D_1$,

which compresses it by a subterranean pipe from the other side of the tunnel, where it meets the pipes of a heater, $E_1$, $E_1$; after

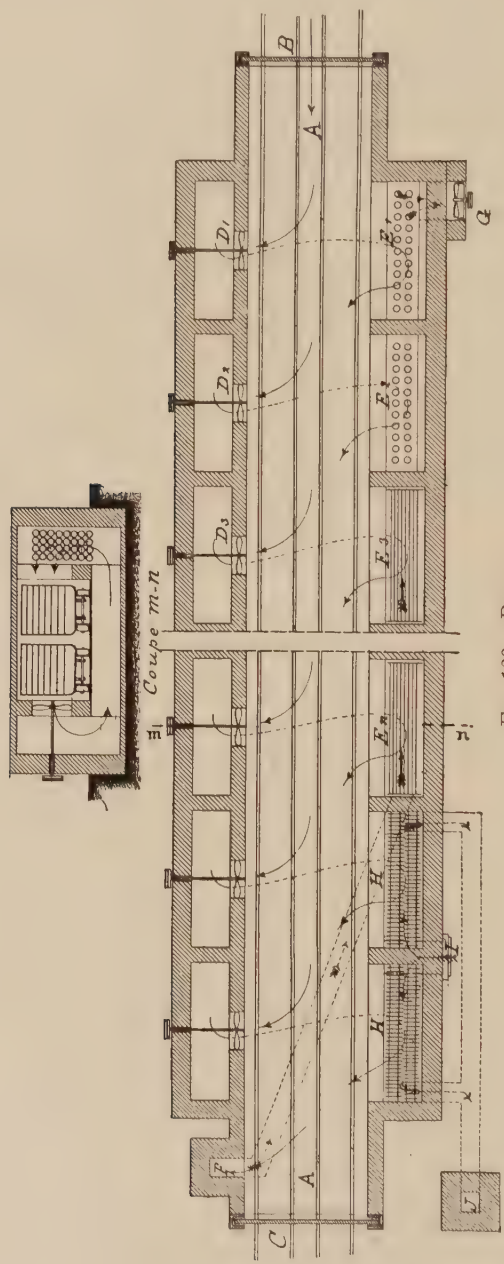


Fig. 130.—Dryer.

being heated in contact with them, it re-enters the tunnel, which it traverses obliquely, being drawn in by a second ventilator, $D_2$,

which compresses it likewise, in order to force it to pass on a second calorifer, $E_2$, and so on. The air then follows a helicoid path, becoming more and more heated as it advances, before going out, near the door *C*, by a side opening, *F*. There, taken in by a ventilator, *G*, it traverses the heaters, *En* . . . . $E_3$, $E_2$, $E_1$, where it gradually loses its heat, by transmitting it to the air circulating in the tunnel. The water vapour which it contains is condensed while restoring the latent heat of evaporisation, and goes out from the drying stove in the liquid state. Finally, the air escapes at *G*, and at a slightly raised temperature.

The two or three last heaters, *H*, are heated by a special stove, *I*, the gas of which escapes by a chimney, *J*.

All these drying stoves, having the form of tunnels, are only used in brickworks and tile works. Some additional details on this subject will be found in Chapter IX.

**127. Drying by Absorption.**—It has been seen in the preceding chapter of what use plaster moulds are in making pottery ware, and how they assist in the drying of bodies. The absorbing properties of the plaster act exactly in the same way as evaporation in a dry atmosphere. The body gives off by capillarity a part of its moisture to the plaster, and this action is the more powerful the drier the plaster is and the thicker the mould.

The making of the moulds needs special care, because it is essential that the plaster should always have the same consistency, so that its absorbing power may be always the same. If, of two moulds made on the same model, one has been made with thick plaster and the other with thin plaster, the latter will be more absorbing, it will thicken the body more quickly, even during the making, and will give denser wares having less shrinkage. This defect will be more serious if, for a mould of large dimensions, it has to be mixed several times with plaster, without the precaution being taken of each time adding the same proportion of water. Certain parts of the object could then dry more quickly than others, which would cause warping. It is, therefore, better in the making of moulds to apportion the plaster and water to the volume in the proportions which practice has proved to be the best.

On the other hand, as the thicker a plaster mould is the more water it can absorb, it is well to proportion this thickness to that of the wares. If the latter have narrow parts beside thicker parts, it is necessary to take this into consideration, failing which some would dry before others, causing warping and even cracks. This drawback could also be provided against by moistening before making certain parts of the mould, to make them less absorbing.

Finally, it is desirable, in the form to be given to the moulds, to take into consideration the shrinkage of the body, which must always be allowed to take place freely. When the shape of the object would be opposed to allowing this condition to be fulfilled, the mould must be made in several pieces, so as to be able to remove, after the making, those which would impede the shrinkage.

If a mould were too absorbent in consequence of the great porosity of the plaster or its too great thickness, it would produce the same difficulties as a too rapid evaporation. The remedy would consist in either diminishing the thickness or in mixing the plaster more strongly, or finally in moistening it sufficiently. The only difference between drying by evaporation and that by absorption consists in this: the latter cannot be given a complete drying. It, perforce, stops at the moment when the humidity of the plaster becomes equal to that of the body. It follows that drying by absorption must always be completed by drying by evaporation. Two processes are employed for this purpose, according to the size of the ware, the nature of the body, and the arrangement of the manufactory. In the first, which is especially applicable for large pieces in plastic bodies for small outputs, the article made is left to dry for some time in the mould in the inside of the workshop where it is made; then, when it has obtained sufficient consistency to enable it to be taken from the mould, it is placed on the shelves, and its drying by evaporation takes place by means of one of the methods indicated previously. In the second process, which is employed chiefly for the manufacture of a large number of small pieces, the mould containing the article made is at once placed in an artificial dryer, where the drying takes place simultaneously by absorption and by evaporation; but the latter is also accomplished by taking out the object from the

mould, and by placing it in a drying room so that it may lose its last traces of moisture.

The moulds themselves, after having been used, should be dried so as to remove the water which they have absorbed. This drying is much easier than that of bodies. It is done either by aeration or in the same drying rooms which are used for the *bodies*. But it often becomes useless when the second process is employed, which has just been indicated. According to the shape of the moulds and the degree of consistency of the body during the making, the drying of the moulds must be done after each moulding, or, which is most frequently the case, it is only proceeded with after two or several operations.

# CHAPTER VI.

## GLAZES.

SUMMARY.—§ 1. *Composition and Properties:* Constitution of Glazes—Chemical Composition — Action of the Glaze on the Body — Classification and Terminology.

§ 2. *Raw Materials:* Silica and Silicates—Boracic Acid and Borax—Alkaline Salts—Compound Alkaline Earths—Oxides and Salts of Lead—Oxide of Tin and Tin Ash—Various Materials.

§ 3. *Manufacture and Application:* Preparation of the Raw Materials and Mixing —Fritting and Vitrification — Mixing and Grinding with Water—Application of the Glazes.

### § 1. COMPOSITION AND PROPERTIES.

**128. Constitution of Glazes.**—Glazes[1] are vitreous coatings with which we can cover the bodies, either to decorate them or to make them impermeable. The vitrification ought to act upon the body itself under the influence of heat. Their chemical composition is nearly as variable as that of the bodies, but, nevertheless, we may consider them as glass in the widest meaning of that word.

"The name of glass is given to a substance which is fusible at a high temperature, brittle, hard, transparent or opaque, insoluble in water, capable of resisting the action of acids even when concentrated, formed by the combination, in varying proportions, of a silicate of soda or of potash with one or several of the following silicates: silicates of lime, magnesia, baryta, alumina, iron, zinc or lead." This definition, given by MM. Appert and Henrivaux in their work on *Glass and Glassworks*, does not altogether apply to glazes. These latter, in fact, are not solely composed of silicates; they sometimes contain quite as much borates, seldom phosphate of lime, and among the bases we must add oxide of tin, while sometimes the alkalies are quite absent. Lastly, their fusibility is much more variable than

[1] French *glaçures*, from *glacer* (to freeze), *glace*, Latin *glacies* (ice).

that of glass properly so called. Sometimes they vitrify at a temperature lower than that for fusing crystal; sometimes, however, they need the temperature high enough for burning porcelain.

As in the case of glass, it is not certain as to the molecular constitution of glazes. Some people think that the different bases of which they are composed are dissolved from silicates or borates to an alkaline silicate, others think that they are mixtures of different silicates or borates in definite compositions. It is difficult, in the present state of our knowledge, to decide this question, but it is necessary to make two important observations on the subject.

Glazes, like glasses, are amorphous bodies, that is to say their molecules have not taken a certain grouping together, as is the case in crystallized bodies. They thus present a remarkable exception to the laws of the molecular composition of bodies, which ought, for the greater number of them, to be attributed to the presence of alkaline silicates, the crystallisation of which, being very difficult to obtain, is only produced when the relative proportions of the silica and the alkali correspond to the relations which are determined by their atomic weight. It is only exceptionally that one can notice in glazes the phenomenon of crystallisation, which generally has the effect of making them opaque. It occurs then from the formation, in the interior of the mass, of crystals which have a definite chemical composition. It is thus that sometimes the presence of "wollastonite," a silicate of soda and lime, can be detected, or of "oligoclase," a silicate of soda, alumina and lime. This defect is obviated by increasing the proportion of the alkalies, by introducing several bases into the glaze, and by not giving this latter a definite atomic composition, the presence of several bases having precisely the effect of making a regular grouping of the molecules more difficult. This observation shows, on the one hand, the important place of alkaline silicates, and, on the other, the mistake into which those potters have fallen who have wished to give glazes a definite chemical formula.

In the second place, if certain substances are introduced into glazes they do not combine, but remain suspended in it and thus render the mass opaque. The oxides of tin and zinc, alumina and phosphate of lime are of this kind; these bodies are even used to destroy transparency. But one may also remark that in the

degree that the temperature for fusing the glaze is increased, these bodies have in the same measure a tendency to combine, at least partially, and to be distributed or dissolved into the amorphous mass.

Quartz acts differently; if some of it is added to a silicious glaze, that is to say, one in which all the bases are saturated with silica, it dissolves in it without altering the transparency. But, under certain circumstances, it may separate afresh by crystallising in the middle of the mass in the form of tridymite. The change which takes place in its constitution, which is characterised by the alteration of its density from 2·6 or 2·7 to 2·2 and 2·3, shows that it has not been simply dissolved, but that this has been accompanied by an action on the bases, in spite of their state of saturation.

From the foregoing observations we may conclude that glazes are amorphous substances, formed of alkaline silicates and borates, earthy or metallic alkalies, which are found sometimes in solution, sometimes mixed, but their molecules are not in regular groupings. They are liable to dissolve certain substances, noteably quartz, and of keeping others only suspended. In fact, their molecules have a tendency, under certain circumstances, to group themselves together, at least partially, so as to form definite compositions which crystallise in the middle of their mass, making it opaque.

**129. Chemical Composition.** — Silica is the preponderating element in glazes; we have seen that it may be found either combined in the bases or in solution, but it always has a density of 2·2 or 2·3. Its amount may vary from 25 to 75 per cent.; the higher it is the more the temperature for fusing the glaze is increased.

*Boracic acid* plays the same part as silica, but the borates are much more fusible than the corresponding silicates. It makes the glaze harder and more brilliant, but it acts upon the colour of certain metallic oxides, as may be seen in the chapter relating to decoration. On account of its high price, it is only used for certain fine glazes, its proportion scarcely exceeding 10 per cent.

*Phosphoric acid* is less used. It is only found in glazes in the form of phosphate of lime, suspended in the mass.

*Alkalies.*—Soda and potash with silica and boracic acid form very fusible compounds, but they are soluble in water; also they

cannot be used alone, and other bases must be added to them to form numerous insoluble combinations. They have the advantage that they make the glazes more pure and transparent, but they give the metallic oxides special colours. Their proportion may be as high as 25 per cent. Potash makes more fusible compounds than soda does.

*Lime* is often used to make the double silicates and borates of alkalies and lime unchanging and beautifully transparent. It has, however, a tendency to cause the formation of crystals. Alone, it may make, with boracic acid, a fairly fusible glass; but with silica, at a high temperature, it only forms a whitish mass, which is more or less translucid. Its proportion may be as high as 20 per cent.

The other alkaline earthy bases possess the same properties as lime, but with different degrees of fusibility. *Magnesia* is more refractory; *strontia* more fusible; and *baryta* more solvent than strontia. The equivalents of these bases being as follows:—

| | |
|---|---|
| Baryta . . . . . | 153·20 |
| Strontia . . . . . | 103·50 |
| Lime . . . . . | 56·00 |
| Magnesia . . . . . | 40·00 |

one sees that they vary in the same order as their fusibility.

*Alumina* is found in glazes principally in the form of silicate of alumina. In a small proportion, it forms with alkaline silicates glasses which are transparent, hard and very slightly inclined to crystallise. In larger proportions it remains in suspension, making the glazes more or less opaque or rather translucid. It does not combine so well with alkaline borates or silicate of lead. In every case, its introduction into a glaze has the effect of noticeably diminishing the fusibility.

*Oxide of lead*, on the other hand, is a great deal used to increase the fusibility. It forms with silica and boracic acid glasses which are insoluble in water and cannot be attacked by acids, provided they contain, at least, one equivalent of boracic acid or silica to one equivalent of oxide of lead. It has a slight tendency to crystallisation, but it acts on the colouring of certain metallic oxides.

*Oxide of bismuth* acts the same as oxide of lead, making still more fusible compounds.

*Oxide of tin* does not form a glass in glazes; it remains suspended in them, making them opaque. This opaqueness, however, is inclined to diminish with the temperature. It is this property which causes it to be very often used in the manufacture of opaque glazes.

*Oxide of antimony* fulfils the same part as oxide of tin does, though it is more fusible; but, although colourless in itself, it can impart yellow colouring to glazes.

*Oxide of zinc* also remains in suspension in silicious glazes, but in boracic acid it dissolves. In spite of its whiteness, it often modifies the colours of the other metallic oxides. It is very slightly fusible.

The *colouring oxides*, which are introduced into glazes to give them decorative properties, will be studied in Chapter VIII.

**130. Action of the Glaze on the Body.**—We have seen that glazes can dissolve quartz and keep other substances suspended in their mass. Thus, it is natural that, under certain circumstances, they should act as flux or solvent on the body at the moment of their fusion. But, in order that this action may take place, it is necessary for the temperature of fusion to be kept up sufficiently long.

Under these conditions, and when the glaze is sufficiently basic, especially if the proportion of the alkalies in it is raised, it can dissolve a certain proportion of the free silica.

It can act at the same time against the oxide of iron which certain bodies contain, which, by spreading into the mass, may cause yellowish spots in them.

When this action of the glaze on the body takes place, it causes the modification of the chemical composition of the glaze, which thus becomes more silicious. Yet, we must not exaggerate its importance, as some potters do, so as to make the definite formula which they give to glazes correspond with their true composition. On the other hand, it would be equally erroneous to neglect it when one is studying the agreement which ought to be found between the respective expansions of the body and the glaze. There is always, or, at least, there ought always

to be between the two an intermediate zone, in which they are mixed up, and which serves as a transition point.

131. **Classification and Terminology.**—Glazes differ from one another chiefly in their chemical composition, which affords the means of deciding their most important physical properties, *e.g.*, hardness, transparency, solubility, etc. All classifying then ought to be based on this composition, which, while taking no account of certain substances in small proportions, is a very simple method of being able to characterise them by two or three (very seldom four) principal bodies. It is advisable here to observe that, as all glazes contain silica, there is no need to mention it except when it is found in a preponderating proportion. Thus an alkaline plumbiferous glaze is a silicate of alkali and of oxide of lead.

Certain potters have proposed to classify the glazes, according to the relative proportions of the acids and bases which they contain, into acid, neutral or alkaline glazes. This distinction, which does not take into account the different properties of the two acids and of the various bases, only rests on theoretic considerations which are rather disputable; besides, it has not been taken up.

It is preferable in common practice to keep to the following terms, which have been sanctioned by use:—

One designates under the name of *soft glazes* (Fr. *vernis*)[1] the transparent glazes fusible at a low temperature, only slightly thick, generally very plumbiferous, which are used to cover over certain earthenwares (*faïence*).

*Enamels*[2] (Fr. *émail*)[3] are glazes which melt at a temperature higher than soft glazes, and generally of greater thickness. One distinguishes *opaque enamels*, stanniferous and usually plumbiferous, from *transparent glazes*, which are plumbiferous or alkaline. They are specially used in the manufacture of fine earthenware, and more usually in the decoration of all pottery.

Finally, one calls *hard glazes* (*Fr. couvertes*) those glazes which are transparent, hard, of medium thickness, melting at a high

[1] From the Latin *vitrum*, glass.

[2] In English ceramics it is usual to confine the term "enamel" in connection with glazes to those which are opaque.—W. P. R.

[3] From the ancient German *smelzan*, *smaltjan*, to melt; low Latin, *smaltum*.

temperature, nearly always containing alumina or an alkaline earthy base, which are used to cover over vitreous pottery, or certain kinds of faience made from fine body.

These names of soft glaze, enamel, hard glaze, not having a rigid significance, ought not to be considered as the terms for classifying, but as synonyms of the word glaze, and it is wise, when it is desired to show their precise nature, to accompany them with the name of the principal substances which enter into their composition. Thus we should say: a boracic alkaline glaze, an alkaline plumbiferous enamel, a calcareous hard glaze, etc.

In glassworks one includes under the name of enamel "all vitreous materials, transparent or opaque, coloured or colourless, which are used for covering over the body".[1] We see that in pottery this general definition is applied to the word glaze, and that the name of enamel has assumed a narrower meaning.

Finally, in considering the glazes from the point of view of their action on the colouring oxides, one divides them into *plumbiferous*, *boracic* and *alkaline* glazes, according as one or the other of these substances is in a larger proportion, and may influence the colouring.

## § 2. Raw Materials.

**132. Silica and Silicates.** Silica is usually introduced into glazes in the form of quartzose sand, as pure as possible. Usually a sifting and sometimes a washing are the only preparations that are necessary. But it is essential to know the proportion of alkalies that the purest sands always contain, in a very small proportion it is true, but which, considering the large amount of sand in most glazes, may exert a certain influence on them. When one has no suitable sand at hand one may use quartz or flint, but in this case it is necessary to calcine and powder them first. For the other directions relating to silica turn to Chapter II. (Art. 38).

Among the silicates the *feldspars* are those most used in the manufacture of glazes. We have seen (Art. 44) that these are silicates of alumina and alkalies, usually containing a small proportion of lime, oxide of iron and magnesia. The purest sorts,

[1] *Glass and Glassworks*, by MM. Appert and Henrivaux, in the *Encyclopédie Industrielle*.

particularly those which are free from oxide of iron, are the only ones to be used. Among the feldspathic rocks *pegmatite* from Saint-Yrieix and *Cornish-stone* from Cornwall are equally very much used. All these stones ought to be finely powdered before being mixed with the other ingredients of the glazes.

In certain glazes one adds also *kaolin earth, plastic clay* and *grog* or *calcined clay*. These materials, which have been already described, lessen the fusibility to a large extent, and usually impart to the glaze an opaline translucidity.

The *glasses*, such as are generally made in glassworks, are sometimes used for common glazes. They have the advantage of being much more easily worked than feldspars, and of making it unnecessary to frit the alkalies, as we shall see in the account of the manufacture of glazes. Their only defect is that they have rather various compositions, so that one must make analysis if one wishes to get an exact mixture. The following are the usual limits to the variations in their composition :—

*Window Glass.*

| | |
|---|---|
| Silica | 73·3 to 69·6 |
| Alumina, oxides of iron and manganese | 1·8 ,, 0·7 |
| Lime | 13·2 ,, 11·6 |
| Alkalies | 16·5 ,, 12·3 |

*White Bottle Glass.*

| | |
|---|---|
| Silica | 72·3 to 57·3 |
| Alumina, oxides of iron and manganese | 5·3 ,, 2·2 |
| Lime, magnesia, baryta | 30·7 ,, 8·6 |
| Alkalies | 16·9 ,, 5·6 |

*Crystal.*

| | |
|---|---|
| Silica | 61·0 to 51·0 |
| Alumina, oxides of iron and manganese | 2·0 ,, 0 |
| Lime | 4·0 ,, 0 |
| Alkalies | 13·7 ,, 6·0 |
| Oxide of Lead | 38·1 ,, 28·2 |

**133. Boracic Acid and Borax.**—Boracic acid is found in the form of crystals containing a large proportion of water ; it corresponds to the formula $BO^3, 3HO$. It easily melts in its water of crystallisation; but it must be fairly well heated to make it anhydrous.

It is sold either in the form of *refined boracic acid*, in fine white flakes containing 96 to 97 per cent. of boracic acid, or under the name of *Tuscany boracic acid*, the crystals of which are larger, yellowish, and only contain from 85 to 90 per cent. The impurities

of the latter consist of hydric sulphate of ammonia, silica hydrate, organic matter and traces of lime. It is good to test them, because boracic acid is rather often adulterated. This test is very easily made by dissolving in boiling water, filtering and weighing the residuum. Pure hydrated boracic acid contains 56 per cent. of boracic acid and 44 per cent. of water.

Boracic acid is generally used in the form of borax, that is to say, of hydrated borate of soda, represented by the formula $NaO, 2BO^3, 10HO$. When exposed to the air, the glassy crystals of borax become cloudy and whitened on account of the evaporation of a part of the water of crystallisation. Heated to a low temperature, this water completely evaporates, and the borax falls in the form of a white powder. At a slightly higher temperature it melts and becomes a vitreous mass. It is found, in the form of borate of soda and of lime more or less impure, in the north of Chili, and it is treated with carbonate of soda to get rid of the lime.

Borax is generally used in the form of *refined borax*, being purified by several successive crystallisations. It is then noticeably pure and contains 37 to 38 per cent. of boracic acid to 16 to 17 per cent. of soda; the remainder is water.

One uses also natural borax called *tineal* and *American borax*, which sometimes contain rather a large proportion of impurities, and the composition of which is variable.

The same as for boracic acid, it is also wise to test borax, because, besides the natural impurities which it contains, it is often mingled with foreign substances. This experiment is made by dissolving a definite weight of borax in water, colouring the solution with blue litmus, and pouring into it a standard liquor of sulphuric acid, it may be, for example, 100 grammes of acid at 66° per litre. One takes note of the number of cubic inches of standard liquor that it is necessary to add to the solution so that its colour is changed to the yellow of onion peel. If, on the other hand, one has made the same experiment with an equal weight of pure borax, the relation of the two numbers of cubic inches thus obtained shows the proportion of pure borax in the sample experimented upon.

**134. Alkaline Salts.**—*Carbonate of soda* ($NaO, CO^2$) con-

tains when *calcined*, 58·5 per cent. of soda and 41·5 per cent. of carbonic acid. One can buy soda that is sufficiently pure of the manufacturers. It must not be kept in damp places, because it is hygrometric. It is also sold in the form of large *crystals*, with the formula $NaO, CO^2, 10HO$, that is with a composition of 21·7 per cent. of soda, 15·4 per cent. of carbonic acid, and 62·9 per cent. of water. This kind was formerly preferred to the first one, because of its purity: actually this preference is now hardly justified; but, anyhow, one must avoid using the carbonate of soda which comes from ashes, as this is always very impure.

*Carbonate of potash* ($KO, CO^2$) contains, when pure, 68 per cent. of potash and 32 per cent. of carbonic acid, but this condition is seldom found, and it is wise to test it. It is very hygrometric and ought always to be dried before being used. That which comes directly from the ashes of the vines is very impure and cannot be recommended.

*Sodium chloride*, or sea salt ($NaCl$), is sometimes used in glazes, but its most frequent use is for enamelling stoneware by volatilisation. One can use, for this purpose, artificial salt, that is to say, that which has not been subjected to duty.

*Sulphate of soda* ($NaO, SO^3, 10HO$), which is very much used in glass making, is much less used in pottery. It is necessary to calcine it before using it, because of its large proportion of water of crystallisation.

*Nitrate of potash* ($KO, NO^5$), saltpetre, nitre, was formerly the salt of potassium par excellence. Now, one only uses it in pottery, as one can manufacture the carbonate sufficiently pure; but, as it decomposes to a dull red, while disengaging oxygen, it is used to purify glazes which contain organic matter. It is sold commercially in the form of small crystals, generally fairly pure.

It is easy to test the quantity of soda or potash contained in the carbonates, by following the method already described for borax. A certain weight of salt being dissolved in water, the solution is coloured with blue litmus, and to it drop by drop is added a standard liquid of sulphuric acid, until the liquid becomes an onion-peel colour. If the standard liquid contains,

for example, 1 gramme of sulphuric acid at 66° to 10 cubic centimetres, and if $n$ is the number of cubic centimetres added by means of a graduated burette, the proportion of carbonate of soda will be $\frac{n \times 53}{49}$, these two numbers representing the relation of the equivalents of carbonate of soda and sulphuric acid. For carbonate of potash the formula will be $\frac{n \times 69}{49}$. If the sample tested contains a mixture of carbonate of soda and potash, this method is no longer applicable, and one must have recourse to analysis by bichloride of platinum (Art. 50).

*Alum* ($Al^2O^3$, $3SO^3$; KO, $SO^3$, 24HO) has sometimes been used to introduce potash and alumina into glazes. It is, in fact, a double sulphate of alumina and potash, sold either in the form of crystals containing a large proportion of the water of crystallisation, or in the form of burnt alum. It rather often contains oxide of iron, but one can purify it by successive crystallisings. When pure, it contains about 20 per cent. of alumina and 18 per cent. of potash.

**135. Compound Alkaline Earths.** — *Lime* is introduced into glazes in the form of the carbonate and sulphate; it is seldom that one uses caustic lime.

Carbonate of lime (CaO, $CO^2$) decomposes slowly at a sufficiently high temperature, giving 56 per cent. of lime (Art. 45).

It is usually found sufficiently pure in the form of white marble or of Meudon or Spanish white, so that it need not be tested. However, if one wishes to test it, it is sufficient to dissolve in nitric acid a certain quantity of the carbonate, to saturate the solution with ammonia, filter it, and precipitate the lime by the oxalate of ammonia into oxalate of lime.

Sulphate of lime or gypsum is sold in the form of crystals or of plaster in powder. In the latter case it is somewhat impure and contains carbonate of lime, the presence of which is easily detected by the giving off of carbonic acid, which it does when attacked by an acid. Crystallised gypsum is a hydrated sulphate of lime (CaO, $SO^3$, 2HO), which contains in a pure state 31·86 per cent. of lime and 46·51 per cent. of sulphuric acid, which is only given off at a high temperature.

*Magnesia* may be added to glazes in the form of dolomite, a mixture of the carbonates of lime and magnesia, or of talc and magnesite, which are hydrated silicates of magnesia. These substances have been described in Chapter II.

*Baryta* is only used in the form of sulphate of baryta or heavy spar ($BaO, SO^3$), containing, in a pure state, 65 to 66 per cent. of baryta; it is a mineral, somewhat scattered in nature. One might also use the carbonate (witherite).

*Strontia* is scarcely ever employed. One finds it in Sicily in the form of crystals of sulphate of strontia, generally mixed with sulphur crystals, or in Scotland in the form of carbonate (Strontiniate).

**136. Oxides and Salts of Lead.**—The oxide of lead is used in the form of litharge, red lead, white lead and galena.

*Litharge* (PbO), or lead monoxide, is sold in the form of brilliant lamellar crystals, or of reddish-yellow powder. It is obtained by heating metallic lead in air, then by melting and allowing the oxide thus produced to crystallise. If the cooling is rapid, then one obtains reddish-yellow crystals, sold under the name of yellow litharge; if, on the contrary, it is slow, the crystals, of a bright red, are called red litharge.

By oxidising lead, without afterwards melting and crystallising it, one obtains an amorphous production known by the name of *massicot*, which has the same composition as litharge. Massicot may also be prepared by calcining nitrate of lead; it is then almost pure monoxide of lead.

In trade one finds English, French and German litharge. The first is the best, as it contains only traces of iron and copper, and the last is the most impure.

Nevertheless, because of the adulterations to which sometimes litharge is subject, it is always wise to verify its purity by experiments. If it is treated with acetic acid it ought not to produce any effervescence, as that indicates the presence of the carbonates of lead, baryta or lime. In order to detect the presence of other foreign substances, litharge is attacked with dilute nitric acid: it ought to dissolve entirely in it. If there is any residuum, it is usually antimonic acid, sulphate of baryta, or even ochres, sand or powdered terra cotta. It is next filtered, then the filtered solution

is dried, mixed with sulphuric acid, evaporated afresh, and at last treated with water, which dissolves all the sulphates except those of lead and baryta. The solution may be evaporated to weigh the residuum, if there is any. In any case a blue or green colour shows the presence of copper or iron.

*Red lead* ($Pb^3O^4$ or $2PbO, PbO^2$) is a plumbate of lead monoxide, obtained by heating massicot to about 300°. It is found in the form of a beautiful red powder, which darkens in the light. Heated to a red heat it is changed to lead monoxide with the freeing of oxygen: 100 parts by weight of pure red lead give 97·37 parts of the monoxide. But red lead contains always a noticeable proportion of massicot, even if it is heated several times. Thus, red lead fired once contains 50 per cent. of it, and that called "eight fires," that is to say, heated eight times, still retains 25 per cent.

To test red lead it is treated, as has been before described for litharge, by dilute nitric acid, which ought not either to produce any effervescence or to leave any residuum. This solution being evaporated, one can get it back again with neutral acetate of lead, which dissolves the lead monoxide and leaves a residuum of dioxide ($PbO^2$), which ought to have a clear brown colour. English red lead is sold in barrels of 6 to 7 hundredweight; the French kind is sold in barrels of 8 to 9 hundredweight, and is usually of a browner colour. The best qualities only ought to be used in glazes; these are called red lead for glass work.

*White lead* ($PbO, CO^2$) is a carbonate of lead, which is also found in a hydrated form, $2(PbO, CO^2)\ PbO, HO$; it is then wise to dry it before mixing it with the other materials that enter into the composition of glazes. It decomposes in heat, carbonic acid is given off, and there remains lead monoxide.

Pure anhydrous carbonate gives 83·52 per cent. of the monoxide.

White lead is manufactured by different methods, called Dutch, Austrian, English and French, which are all based on the combination of metallic lead with carbonic acid, either directly or by the medium of acetic acid. It is somewhat frequently adulterated by the addition of sulphate of lead, sulphate of baryta, plaster and chalk. In order to detect these mixtures, one treats the sample of white lead with carbonate of ammonia, which decomposes the sulphates of lead and lime, but not the sulphate of baryta.

Then, by filtering, one gets a residuum containing the sulphate of baryta and the carbonates of lead and lime. By treating this with nitric acid one dissolves the carbonates; the sulphate of baryta can be separated by filtration, and can be weighed. The filtered solution is afterwards evaporated till dry, treated with diluted hydrochloric acid, which precipitates the lead as a chloride. This is filtered, then the liquid is treated with an excess of ammonia to gather up the last traces of the oxide of lead that remain soluble, and, after having again filtered it, the lime is precipitated by means of the oxalate of ammonia.

*Lead ore*, or galena (PbS), is a grey mineral with a metallic lustre, in the form of granulated layers, sometimes compact. Chemically, it is a sulphide of lead, containing in a pure state 13·39 per cent. of sulphur and 86·61 per cent. of lead. Burnt slowly in air to a dark red, it is changed into sulphate of lead ($PbO,SO^3$), which itself decomposes at a higher temperature and leaves the lead monoxide. 100 parts of pure sulphide gives 93·30 of monoxide. The ores of galena are somewhat diffused in nature, but they are seldom pure, and almost always mixed with gangue (veinstone). Their variable composition, as well as the inconveniences which may result from the liberation of sulphurous fumes in the furnace, cause them to be used only for common ware, although they are cheap.

**137. Oxide of Tin and Tin Ash.**—The *oxide of tin* used in pottery is the dioxide ($SnO^2$), or stannic acid, which is sold in the form of a white powder and generally in a hydrated form ($SnO^2,HO$). It only decomposes at a red heat, to give a slightly yellowish powder of anhydrous oxide of tin.

It can be prepared fairly simply by adding nitric acid to the metal tin; this decomposes, and a part of its oxygen combines with the tin, giving oxide of tin, or rather metastannic acid, an isomeric form of stannic acid. This distinction has no importance in its use for glazes; it is sufficient to wash properly the white powder thus obtained, and to powder it very well by breaking it up in water. Generally, however, it is better to buy the oxide of tin, testing that it is absolutely pure. In trade a distinction is made between oxide of tin manufactured in acid, as we have just described, and that prepared in the fire,

which is obtained by the oxidation in the air with the action of heat on the metallic tin. In place of a rather long complete analysis, the sample may be first washed and tested to see if the water is cloudy and does not dissolve any foreign substance, the oxide of tin being absolutely insoluble. Then it is heated, in a closed crucible of fireclay, to a strong, red heat; the powder ought to remain not united, having lost at most 25 per cent. of its weight, of a light yellowish colour, and the crucible ought not to show any traces of vitrification.

Oxide of tin is also often used in the form of *tin ash*. This is a stannate of oxide of lead into which tin enters from 15 to 50 per cent., and lead from 85 to 50 per cent. It is usually manufactured, because of its variable composition, in the pottery works.

For this the two metals are mixed together, as pure as possible, in the proper proportions, and submitted in an open vessel to the action of the flames of a fireplace. The metals melt and are covered over by a powdery layer of yellowish-white, which is tin ash.

It is usual, during the whole time of the operation, to move the metallic mass about with an iron scraper, and to take off, from time to time, a part of the powder. For a manufacture that is rather important, use is made with advantage of a furnace with a hearth similar to that shown further on, which is used for the vitrification of the glazes, but by arranging a working opening which is large enough. For small quantities it is sufficient to put the metals into wide open fireclay crucibles. Metallic pots, which are sometimes used, have the defect of often mixing oxide of iron with the tin ash. However this may be, this is afterwards washed, to separate the metallic particles that may be left, which have not been attacked, and which, being heavier, are precipitated first. One finishes the manufacture by drying and powdering, which does not need to be done as carefully as that of the oxide of tin.

138. **Various Materials.**—Sometimes *fluorspar*, or *fluorine* ($CaFl^2$), which is a fluoride of calcium, and *cryolite* ($3NaFl, Al^2Fl^3$), or double fluoride of soda and alumina, are used as fluxes. These bodies decompose in red heat; the bases, lime,

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soda and alumina, which form them, mix with the other elements of the glaze, while the fluorine combines with the metal of the silica to form a fluoride of silicon, which volatilises if the temperature is sufficiently high. If such is not the case, or if the glaze is not sufficiently silicious, the fluorine remains separate and may form saline deposits, which spoil the surface. Fluorspar, which is very little used in pottery, is frequently found in thick veins in the metallic strata. Cryolite, which is more widely used, is found in Greenland in the form of crystals of a pearly white, sometimes slightly tinted yellow by oxide of iron. It contains 54·16 per cent of fluorine, 32·73 per cent. of sodium and 13·06 per cent. of aluminium, giving, after being oxidised, for every 100 parts of raw material, 40·73 per cent. of soda and 25·06 per cent. of aluminium.

*Oxide of zinc* (ZnO) may be used to make silicious glazes opaque; it is about of the same fusibility as magnesia.

It is prepared by oxidising metallic zinc, and is sold in the form of a white powder, which is yellowed by calcining, but regains, when cooled again, its previous colour. The best quality is usually fairly pure.

*Oxide of bismuth* acts, in glazes, in the same way as oxide of lead, but it is more fusible.

Lastly, *phosphate of lime*, sometimes used to cause opaqueness, has been mentioned in Chapter II.; it is used for this purpose in glass work, mixed with a small proportion of fluorspar.

## § 3. Manufacture and Application.

**139. Preparation of the Raw Materials and Mixing.**—The manufacture of glazes is done, in its most complex form, by the following operations:—

Preparation of the raw materials.

Mixing.

Fritting or vitrification.

Mixing and grinding in water.

In order that they may be used in the manufacture of glazes, the raw materials ought to be in the form of very fine powders, as pure as possible, and with a composition that does not change in the air,

thus allowing of an exact mixing. The operations through which they must go in order to fulfil these requirements depend on their nature ; they have just been noticed for each material in the foregoing articles, now it only remains to give some general notes on this subject.

*Pulverisation* is done by the different methods shown (Chapter III.) when speaking on the preparation of the body. But it must be observed that, for glazes, it is always very important to avoid mixing with it particles of iron or of oxide of iron, and that it is, consequently, wise only to use pulverising machines, the metallic parts of which do not come in contact with the material to be ground. The methods to use, then, are vertical or horizontal grindstones, mills with blocks, and ball crushers, cased in stoneware, or porcelain, and with balls of the same material or of flint. Pulverisation is done either dry or in water, and is followed out to a greater or less degree of fineness, according as to whether it has to be followed by a second grinding with water or not. As we shall see further on, for hard materials, as quartz, flint, feldspar, spar, cryolite, one can hardly get them very fine, except by grinding them with water.

Dry grinding ought to be carried on with great precautions, so as to avoid the giving off of dust, which is very injurious to the health of the workmen. Hermetic coverings round the apparatus and systems of ventilation are indispensable, and are not sufficiently replaced by wearing masks. By the order of 13th May, 1893, this work is forbidden in France to young people under eighteen years of age. The mineral dusts fix on the mucous of the throat, trachea (windpipe), and bronchus, are incrusted there and cannot be entirely driven away by the fits of coughing that they provoke. Their presence soon sets up acute, or chronic, inflammation, at the same time as the wounds they make predispose one to the absorption of the bacilli of infectious diseases. Also, among the workmen employed in the badly arranged pulverising workrooms a mortality exists much above the average, principally due to tuberculosis.

This injurious action of the dust is much aggravated when it contains plumbiferous compounds, and particularly white lead. Then it may produce special affections, called by the name of lead-poison-

ing, which commences with colic, sickness, and an obstinate constipation, which ends, if not cared for, in developing cachexy, in consumption, and sometimes in death. The preservative arrangements already described are not, in this case, always sufficient to avoid all contamination. It is necessary to frequently change the male adult worker, who alone ought to be employed, and to give him every day one or two quarts of milk. At the first symptoms, it is wise to add to this diet, by giving from 0·6 gramme to 1 gramme a day of iodide of iron or of potassium for six to ten days, then leave it off for two or three weeks, and begin this treatment again afterwards if the symptoms of lead-poisoning have not disappeared. In order to avoid all these inconveniences, potters often prefer to buy the raw materials of the glazes in the form of fine powders, as one can always find them in the market.

The methods of *purifying* the raw materials have been described for each of them; there is then no need to go over them again. As to *mingling*, that can be done by weight or by volume, in pots having the capacity of a certain weight. One ought to proceed more exactly than for bodies, and care must be taken to reckon the water and volatile substances—carbonic acid, sulphur, sulphuric acid—which the raw materials may contain, especially the variable amount of hygrometic water or of water of crystallisation which may become the cause of mistakes. The materials which may contain them ought to be dried or well kept in closed places, sheltered from damp.

**140. Fritting and Vitrification.**—When the materials have to be finally ground in water, which is most usual, those must first be made insoluble which are liable to dissolve in the water, that is to say, the alkaline salts, boracic acid and borax. To do this, they are changed by the influence of heat into the insoluble silicates and borates, after having mixed them with silica, lime, oxide of lead, etc., according to the composition of the glaze. In making this mixture one must try to obtain products as fusible as possible, so as to economise the expenses of firing.

On the other hand, it is wise also to avoid having materials of very different densities, which, after being mixed with water, would make them be deposited unequally, and would destroy the homogeneousness of the glaze. This observation applies especially to the

materials containing lead or baryta, which are much more dense than the others. As in the foregoing case, this defect can be repaired by combining them with other lighter substances—silica, lime, etc.

Lastly, it is wise to use this same method when a material is introduced into the composition of a glaze in a very small proportion, which it is more difficult to mix very uniformly with the others.

In all these cases, one commences with a preliminary operation, which is called *fritting* when the materials are simply united under the influence of heat, and which becomes *vitrification* when they are melted to the state of glass. For small productions this is done in crucibles of fireclay, heated in special furnaces. When a sufficient heat has been attained, their contents

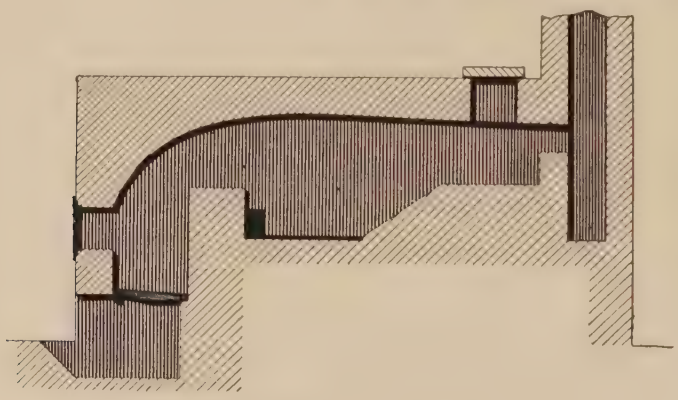


Fig. 131.—Furnace for melting Glazes.

are poured into water to disunite the fritted or vitreous mass, and to make it more easy to pulverise; then the crucible is fitted again to proceed to a second operation. The crucibles can hardly contain more than 22½ lb. of materials to be easily handled. They only bear a small number of heatings, and the furnace ought to be arranged in such a manner as to be able to gather up the glaze which may run out in the case of their breaking. When the materials have to be simply fritted, they unite and form a mass, that can be taken out of the crucible by means of a hook, to plunge it into the water.

In certain cases larger crucibles are used, from which the molten mass is taken by means of iron ladles or rods.

Also crucibles can be used which are pierced at the bottom

with a hole through which the molten mass runs, and is then caught in a pot full of water.

For very large quantities it is wise to use furnaces with a floor, built in different ways, and of which Fig. 131 shows a type that is often used. The materials to be vitrified are brought by an upper opening into the vault, and fall on to a horizontal piece raised from the floor. As fast as they melt, they run on to an inclined plane, to collect at the lower part of the hearth, from which they can be let off by a lateral opening, which while working is closed by a plug of fireclay, carefully sealed. A metal or earthenware spout leads the glass which is formed higher up into a pot full of water, in which it is collected. The working of the furnace is thus continuous, the putting in of the materials and their running off is done at intervals, without stopping the working. The heating is done by a fireplace at one end, while a chimney, with a draught that can be regulated, is at the other end. It is well to get the furnace to the desired temperature before introducing the mixture that is to be vitrified, and to pole the latter to make it homogeneous before running it off.

This furnace is equally suitable for fritting. In this case the hearth is uniformly horizontal. By a lateral working door the mixture is thrown in and levelled, being afterwards taken out by the same opening, when fritted.

In some potteries they do the fritting and vitrification in saggers placed in the kilns for burning the ware, the pieces of vitreous glaze being taken out while emptying the oven. To prevent it sticking to the bottom of the saggers, it is necessary to cover the latter with sand, which remains more or less agglutinated; but this method ought to be looked upon only as a makeshift and not as a regular method of manufacturing it. The same thing applies to the methods of melting the glaze on the hearth, or under the hearth of the burning kiln. As to the method by which the materials are allowed to melt and cool again in the crucibles and then broken up, the mixed up pieces of burnt clay and glaze being sorted out, it is, perhaps, allowable in a laboratory, but, although mentioned by some potters as an industrial method, it is a true barbarism.

In order to carry out the fritting or vitrification, it is essential for the materials to be well mixed, but it is not necessary to powder them very finely. The alkaline salts, boracic acid and borax, may even be rather large, and silica and feldspar may be in the form of sand.

The heating ought in all cases to be done evenly, so as to avoid roasting ash or cinders getting in, but it is especially essential to watch that, in lead glazes, the atmosphere of the furnace be never lowered, in which case the oxide of lead is changed to metallic lead. As to the crucibles and the sole of the furnace, they ought to be made of fireclay which is fairly aluminous, and should not contain grains of free silica, which might be attacked and dissolved by the glaze.

Vitrification is indispensable when it is desired to get very homogeneous glasses, and vitrification ensues when it is necessary to raise the temperature so as to decompose certain sulphates and carbonates. In all other cases fritting is more economical; it becomes even necessary in the manufacture of certain alkaline glazes, which contain chlorides. The alkaline chlorides, alkaline earths or chloride of aluminium which are mixed in the mass, or which are formed by the action of heat, have a tendency, in fact, during vitrification, to become separated, to float and to be violently decomposed when in contact with water, at the time of emptying the crucible or basin. It is the same with the alkaline sulphides.

**141. Mixing and Grinding with Water.**—For the manufacture of certain glazes, and, as we shall see further on, when they are applied by dusting, one may be satisfied with mixing them dry, using substances which are first finely powdered.

It may be done by means of the blunging machines already described, but it is very preferable to do it at the same time as the last grinding in water, which has this advantage, that it makes the mixture very homogeneous and the glaze finer. Blunging ought only to be used when the glaze is bought ready prepared.

Grinding in water is done, most usually, between horizontal grindstones, the lower one being fixed, and the upper having a rotatory motion.

The latter has generally two hollows, through which the glaze enters between the stones. A cock, placed on the lower surface of the grindstone, allows the ground glaze to run out. According to the importance of the ware, the motion to it may be given by hand, or by a machine. Figs. 132 and 133 show the arrangements most generally used. The diameter of the vat varies from 13·77 in. to 15·75 in. for the hand machine, and from 27·55 in. to 39·37 in. for those driven by steam power.

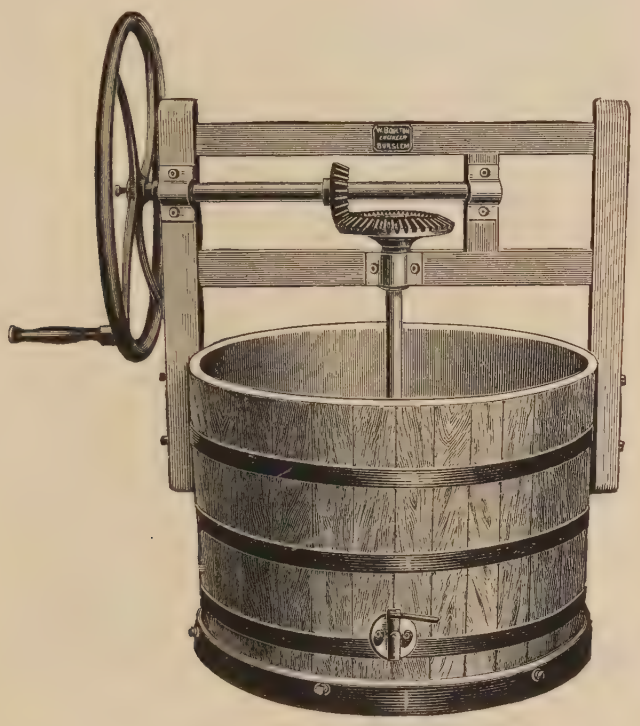


Fig. 132.—Glaze Grinding Machine.

One can just as well use block mills, but now ball grinders or Alsing cylinders are preferred.

Those used for grinding glazes can work charges of 20 to 300 pounds for an expenditure of one-eighth to two horse-power (Fig. 134). The smallest models may be worked by motor power or by hand. The interior covering of the cylinder is of porcelain or stoneware, and the balls are usually flint pebbles. When the grinding is completed, the solid cover is replaced by a grating, which allows the glaze to run out.

If clay enters into the composition of the glazes, it ought, unless

in very small proportion, to be added to the ground mixture in the form of a liquid paste towards the end of the operation, because it would hinder the powdering of the other harder materials.

The glazes ground thus are generally sifted to keep out the grains which are not powdered or the lumps that may have formed. When the sieves are fine, the glaze must be very liquid

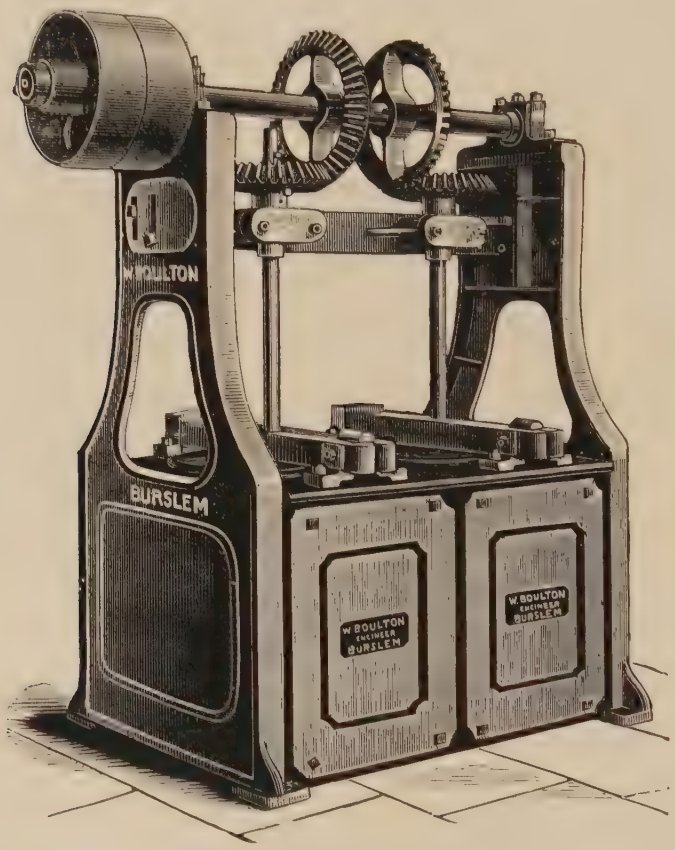



FIG. 133.—Glaze Grinding Machine.

to pass through them, and it is best afterwards to let it settle in basins for it to become of a consistency suitable for application.

It may sometimes happen, on account of the methods of pulverisation employed, that the glaze will contain small particles of iron. In this case it is wise to use an electrical method of purifying it, similar to that which is sometimes used in the preparation of the paste by the liquid way. In this method the liquid glaze is carried into a vat (Fig. 135) con-

taining magnets, some fixed, others movable, which act as agitators. The purified glaze is emptied by a lower cock, while the magnets, which can easily be taken out, are, from time to time, removed, cleaned, and then replaced.

**142. Application of the Glazes.**—The application of the glazes may be carried out on dry ware or on biscuit. In the first case the ware ought to be very dry and sufficiently resisting not to be spoilt either by the manipulation of the application, or by the damp of the glaze. In the second case they have undergone a definite burning at a high temperature, or perhaps they have been simply warmed to make the application easier. Whatever the method employed, it is essential that the body

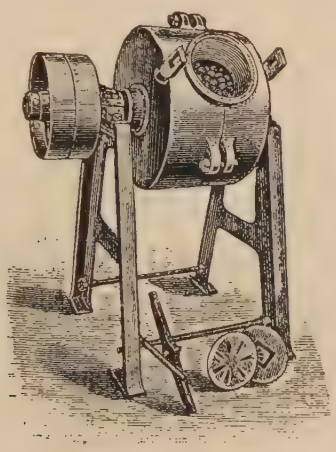


Fig. 134.—Glaze Grinding Machine.

should be sufficiently porous and absorbent for it to soak up the glaze and make it stick.

Six methods of applying glazes are used: dipping or immersing, pouring, sifting or sprinkling, spraying, dusting and volatilisation.

In applying by *dipping* or *immersion*, the objects of clay are dipped into a basin containing the liquid glaze; the clay, in consequence of its porosity, absorbs a certain quantity of water; there is deposited on its surface a thicker or thinner layer of glaze. So that this method, which is very much used, may be successful, it evidently is necessary, on the one hand, that there be a resistant body, sufficiently empty of water, and, on the other hand, a glaze

which has a consistency that corresponds to the absorption of the paste and to the thickness of the layer that one wishes to have. It is only by experiments that one can determine the suitable consistency, which generally is about that of cream.

On the other hand, care must be taken that, when the glaze has

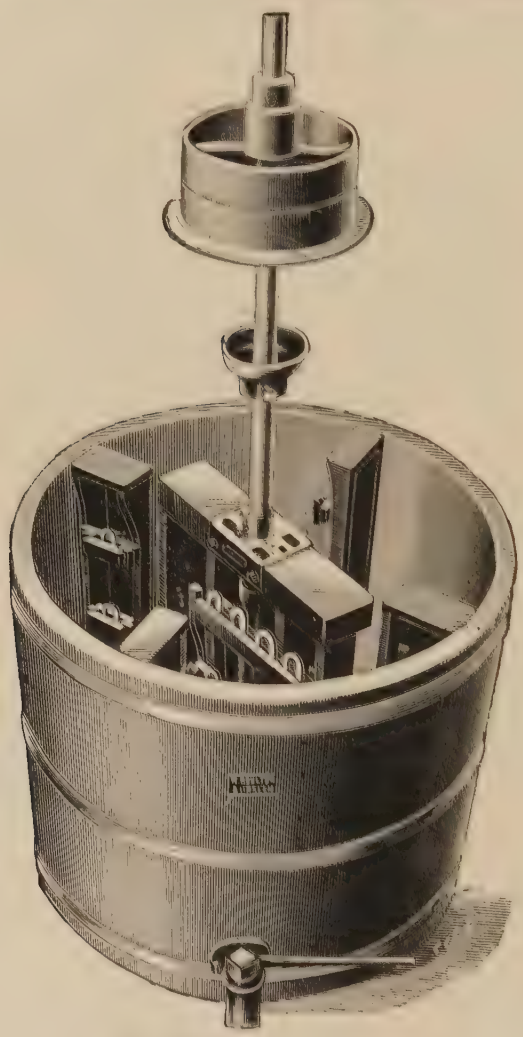


Fig. 185.—Electrical Purifier.

dried on the paste, it should not be too powdery and therefore drop off at the least touch. The glazes into the composition of which slightly plastic materials enter, as clay, lime, white lead, etc., have not this fault, if they have not first been fritted or vitrified. It is for this reason that the fritting or the vitrification ought never to

be carried out with the entire components of the glaze, and that it is best to keep the more plastic materials to add to the others when being ground in water.

The glazes which are not pliant enough have, besides, the defect that they settle unequally and too rapidly, which forces them too often to be excluded. In order to remedy this defect, they may be mixed with vinegar, milk, starch and gums, but this addition often causes other troubles; also on principle it is better to try to find a glaze composition which does not have this fault.

In dipping objects, any dust that may be on them is first carefully got rid of; then they are held with the fingers by the parts that do not need to be covered with glaze. If there are no such parts, it is better to take them up with pincers that have pointed claws, so as only to leave small places on which the glaze is defective. These places can be touched up afterwards with a brush filled with glaze. The methods and vessels used for dipping are essentially dependent on the form of the objects, and here one can only give general directions on this subject.

For pieces that need care retouching is besides inevitable. Either with the finger or a scraper are equalised the parts on which there is too much glaze, as drops, streaks; with a brush some glaze is added to the edges, which generally get too little; finally some parts are cleaned off, feet, plinths, etc., on which the piece ought to stand.

In applying by *pouring*, the glaze is poured over the object, giving it a suitable motion to spread it over uniformly. The unused glazes fall into a receptacle over which the object is held. This method is employed when the glaze is to be put only on the inside or outside of a vessel. It is also used for those bodies which are only slightly porous, which by dipping would not retain a sufficient layer. In this case the glaze ought to be made of a thicker consistency, and, if necessary, its viscidity increased with milk, starch and gums; these materials afterwards disappear in burning. The retouching is done in the same way as in the preceding case.

Application by *sprinkling*, which now is scarcely ever used, consists in sprinkling the objects with liquid glaze. It is done with brushes that have short, hard hair, which are dipped in the glaze;

then they are shaken to get rid of the surplus liquid, and afterwards the ware is sprinkled from them. This method was employed for bodies that were unbaked, friable or covered with reliefs, which could not, without being spoilt, have been dipped or watered.

Really for this kind of work, the application by *spraying* or *diffusion* is preferred, which is done with a small apparatus known by the name of a sprayer. This consists of two tubes at right angles, one of which is in contact with a reservoir of glaze, and the other with some kind of a blast. The openings of the two pipes are arranged in such a manner that the current of air from one makes a draught and a drawing up of the liquid in the other. For small objects the blast may consist simply of an india-rubber ball; for very large surfaces an air pump that can give a pressure of about 7·874 in. of mercury must be used.

The sprayer is placed at a distance of 12 in. to 18 in. from the object, according to its size and the force of the jet. One or the other is moved, or both simultaneously, so as to spread the glaze uniformly over the whole surface. It is wise not to put the whole thickness of the layer on at one time, but to do it in two or several operations, allowing each time one layer to dry before putting on another. This method prevents trickling and gives a much evener thickness.

Besides the method already mentioned, the application by diffusion is a very excellent one for large objects, panels, etc.

In all the foregoing methods the glaze is used as a liquid paste, either thicker or thinner; for the application by *dusting*, on the contrary, it is a dry powder. The objects ought to be of unbaked body that is still damp, so as to retain the glaze with which it is powdered by means of a sieve. This method, which is now scarcely used except for coarse ware with a plumbiferous glaze, has the great fault that it is very dangerous to the health of the workmen because of the dust it makes.

Lastly, the application by *volatilisation* consists in volatilising the glaze by heat inside the kilns used for burning the paste and thus insuring its deposit on the surface of the ware, where it vitrifies by combining with the silica of the paste. This method is only used in the manufacture of stoneware; fuller details will be found in the chapter given up to that ware.

# CHAPTER VII.

## FIRING.

SUMMARY.—§ 1. *Properties of the Bodies and Glazes during the Firing:* General Remarks on Firing—Modifications in the Constitution of the Bodies—The Part played by the different Materials constituting the Bodies with regard to their Fusibility—Modifications in the Volume and the Density—Modifications in the Colouring—Defects in the Bodies after Firing—Firing of the Glazes—Agreement between the Bodies and the Glazes—Experiments in Fusibility and in Firing.

§ 2. *Description of the Kilns:* General Remarks on Kilns. (*a*) *The Fireplaces:* Fuel—Classification of the Fireplaces—Heating by Wood—Heating by Coal with Fireplaces formed of the Ware, with Fireplaces with Gratings, with Furnace Fireplaces—Heating by Gas. (*b*) *The Draught:* Chimneys—The Draught in the Kilns—Regulation of the Draught. (*c*) *Kilns:* Classification of Kilns—Intermittent Kilns with Up Draught, with Down Draught, Horizontal Intermittent Kilns with Single Furnace—Continuous Kilns with Single Firing Chamber, with several Firing Chambers—Horizontal Intermittent Kilns with several Fireplaces—Muffle Kilns. (*d*) *Regenerators.* (*e*) *Construction of Kilns.*

§ 3. *Working of the Kilns:* General Remarks on the Working of Kilns—Charging—Smoking—Firing properly so called—The Atmosphere of the Kilns—Analysis of the Gases—Measuring the Draught—Measuring the Temperature—Cooling and Emptying—Thermic Yield of the Kilns.

### § 1. PROPERTIES OF THE BODIES AND GLAZES DURING THE FIRING.

**143. General Remarks on Firing.**—The firing is the last, the most important, and the most difficult operation in the manufacture of pottery. Its object is, on the one hand, to make the body permanent, to give it resistance or impermeability suitable for its use, and, on the other hand, to vitrify the glazes, by giving them the physical properties of glass.

The temperature to which the body must be raised to make it unchangeable, depends on its chemical composition and particularly on the proportion of fluxes that it contains. It varies from 700° to 1,200° C. For some kinds the impermeability can only be obtained

at a very high temperature, from 1,100° to 1,400° C. The temperature for vitrifying the glazes is still more variable, for it ranges between 500° and 1,400° C. Naturally it must be inferior, or at most equal, to that for the firing of the body. When it is equal, the firing is done in a single operation; when it is lower, first the body must be biscuited, then, by a second firing at a lower temperature, the glaze must be vitrified.

We have seen, by what has been said about the classification of the wares, that terra cotta, faience and earthenware can be manufactured by either single or double firing, according to circumstances. On principle, a single firing ought to be chosen, not only because of the economy, but also because the firing at the same temperature for the body and the glaze makes their union more complete, giving to the ware certain special qualities of resistance. But it is necessary to resort to a double firing if it is intended to apply certain fusible glazes on a hard body which can only be obtained at a higher temperature.

The porcelains are manufactured by a single burning, but the body is nearly always heated first at a low temperature, so as to facilitate the application of the glaze. This first heating ought to be considered as one operation in the manufacture, and not as a firing properly so called.

It will be seen in the following chapter that the fired ware can still be submitted to one or several other firings afterwards, at decreasing temperatures, so as to make the decorations or colours of more and more fusibility adhere to them.

The study of the firing of the wares may be subdivided into three parts. In the first we will examine the modifications made, in firing, in the properties of the bodies and glazes; the second will be devoted to the description of the kilns; the third to the study of the methods of working them.

**144. Modifications in the Constitution of the Bodies.**—We have seen that the bodies which are dry and ready to be fired usually still contain some hygrometric water, which is evaporated in the first stage of the firing, called, rather unsuitably, by the names of smoking or stoving. This water disappears at a temperature slightly above 100° C., at the same time as the organic matters are deprived of their volatile elements, and as the hydrates of silica,

or of iron monoxide, are decomposed, as well as certain hydrosilicates of alumina, such as allophane and collyrite.

If the temperature continues to rise, it does not produce any more modifications till nearly 400°, when pure clay begins, in its turn, to decompose, at the same time as halloysite, lenzinite, cymolithe, bauxite, talc, magnesite, etc. This decomposition may proceed slowly up to 600° C. At that temperature also the carbon from the organic matters is burnt in the oxidising air of the kilns.

Then, as about 700°, the bodies only form an anhydrous mixture of free silica, crystalline silica, alumina, the oxides of iron, alkalies, carbonates of lime or magnesia, and of several silicates including those of feldspar and analogous stones, or of the terra cotta "grog". The other mineral substances which the bodies may still contain are only found very rarely, or in proportions too insignificant to exert any influence on the firing. Up to that temperature all the bodies act in the same way, their constituents remaining mixed, without any chemical affinity for one another.

After 700° the alkalies, then the monoxide of iron (if in sufficient proportions and in the presence of alumina), begin to unite with the free silica to form various silicates. Here we must notice that any of these bases alone could not at this temperature combine with the silica; they can only act when mixed. It follows that in the bodies which only contain a small amount of fluxes the silicates do not begin to be formed until a higher temperature.

The heat continuing to rise, the carbonates begin to decompose, carbonic acid is given off, and the bases set at liberty, joining the alumina and other fluxes, unite with the free silica, forming new silicates, which are more complex, so that at a temperature of about 900° the different bodies present considerable variations in their constitution; it then becomes necessary to divide them into four subdivisions:—

1. *The bodies containing a large proportion of fluxes and not much crystallised silica, at least in which the latter is only found in the form of an imperceptible powder.*—In these bodies nearly all the bases are combined with silica. There remains, however, often still a certain quantity of carbonates that are not decomposed. The crystallised silica has been attacked in its turn, or at least disappears in the midst of the silicates. The bases, and

chiefly the alumina, being entirely combined, the baking may be considered finished. If the raising of the temperature is still continued the mass softens again, rapidly gets out of shape, then melts into the form of a highly-coloured slag, blackish-brown or green, in which may often be noticed some bubbles, which are formed by the carbonic acid arising from the decomposition of the carbonates.

2. *The bodies containing a large proportion of fluxes and having an important amount of crystalline silica in the shape of grains of a fairly large size.*—In these bodies nearly all the bases are equally united with the free silica, but the crystalline silica has remained intact, and forms in the middle of the mass of silicates a sort of rigid skeleton. The burning of these bodies also is finished or nearly so. If one raises the temperature the silicates begin to soften again and to vitrify, but the mass keeps its shape, thanks to the unchangeableness of the crystalline silica. It is only at a temperature of 1,100° to 1,200°, sometimes even more, according to the proportion of the fluxes, that the crystalline silica is attacked in its turn, that the mass becomes misshapen and melts the same as the preceding one does.

3. *The bodies containing a small amount of fluxes, the quantity of crystalline silica being slight or being in an imperceptible form.*—In these bodies the formation of silicates has scarcely begun at 900° C.; we must raise the temperature to nearly 1,200° before the alumina, aided by the small amount of the flux, will combine with the silica. This combination is made the more easily as the proportion of silica is higher, without, however, passing certain limits. It is at very various temperatures, according to the proportion of the fluxes, that the mass first vitrifies, then softens and finally melts.

4. *The body containing little flux, but a large proportion of crystalline silica in coarse grains.*—As in the preceding body, the combination of the silica and alumina only takes place at about 1,200° C. But at higher temperatures the mass vitrifies without softening, thanks to its silicious skeleton. When there is only 1 or 2 per cent. of fluxes, it is melted only at the highest temperature that can be produced in the industry.

It is well understood that these four classes of body are not

clearly marked out, and that wares are met with that have all the intermediate degrees. But, in a general way, it ought to be considered that the *firing properly so called* of a pottery production is finished when all the bases, and especially the alumina, are turned into silicates. If the temperature is raised above this point in firing, either the body softens again, becoming misshapen, and ends by melting in the form of slag, or else it vitrifies without going out of shape, then melts just the same. In this latter case the *vitrification* of the body, which until then was porous, has the effect of making it impermeable.

**145. The Part played by the different Materials constituting the Bodies with regard to their Fusibility.**—*Alumina.*—This base ought to be considered as the refractory element *par excellence* of all the pottery productions. Combined in the form of silicates, it makes them so much the more refractory the more its quantity in them is raised.

*Fluxes.*—There are included under this head, as far as it concerns the bodies, potash, soda, ferrous oxide, lime and magnesia.

Each of these fluxes, taken alone, only combines with silica at a high temperature. But, by only considering always the same proportion of fluxes in regard to the silica, the fusibility increases according as one mixes two, three, four, or if one makes all the five act upon it simultaneously. Thus a mixture by equal parts of potash and soda is more fusible than potash or soda alone; a mixture of potash, soda, and oxide of iron is more fusible than the alkalies alone, etc. The cause of this singular action is actually still unknown, but it is general and is found in all industries in which one has occasion to produce silicates under the influence of heat.

In what concerns the relative fusibility of the five fluxes, according to Richter, one agrees that it is proportional to their chemical equivalents, that is to say, that 47 parts by weight of potash act as 36 of oxide of iron, 31 of soda, 28 of lime and 20 of magnesia. This principle, which seems correct at high temperatures, is not exact at low temperatures and for a high proportion of fluxes, because the temperature at which these different bases begin to have an affinity for the silica is not the same. It is the alkalies which, as has been said before, are

the first to begin to combine; then comes the oxide of iron in the form of monoxide. The order of the other fluxes is not yet quite determined. The iron in the form of dioxide is not a flux; it acts as a refractory material, although in a less degree than alumina.

What has just been said on the subject of fluxes only applies to those which are found in a free state in the body, or to those the combinations of which are destroyed at a low temperature. It is no longer the same when these fluxes are found, in spite of their origin, in the form of stable combinations, in which case the flux only begins to act when the temperature is high enough to destroy them. We have seen that such was the case for the carbonates of lime and magnesia. The same fact is true of the sulphate of lime. The fluxes may equally enter into the composition of the substances, as for example, the feldspars, that are not decomposed by heat, which only begin to act when the temperature is high enough to fuse them.

*Silica.*—The part the silica plays is complex, because, according to circumstances, it increases or diminishes the fusibility, as we have already seen in the foregoing article.

Pure silica is very refractory, of the same standard as alumina; consequently when some silica remains not combined in a body, it diminishes the fusibility. But, on the contrary, we must notice that the silicates are formed as much more easily as the fluxes and alumina are found connected with a very large quantity of silica, and that the silicious silicates are more fusible than the basic silicates.

These two observations allow us to decide what is the part the silica plays. At a relatively low temperature, below 1,000° or 1,100°, it is only the free silica, or the crystalline silica in an imperceptible powder, which is susceptible of being united with the bases and of helping the fusibility. The result is that the coarsely crystalline silica and alumina are two refractory elements. On the contrary, at a higher temperature, the crystalline silica is itself combined and helps to increase the fusibility, so that the alumina remains the only refractory material. If, however, the proportion of the silica becomes considerable enough, not only is it susceptible of neutralising the affinity of the bases,

but there may remain a certain quantity of it uncombined. From this moment this excess of silica again plays a refractory part, as opposed to the silicious silicates with which it is mingled.

These statements about silica and alumina, from the point of view of fusibility, are more clearly shown when the mixtures of the two substances are carried to very high temperatures without the intervention of the fluxes. As long as the proportion of alumina is higher than that contained in pure clay, the mixture in practice is infusible; then the fusibility increases at the same time as the proportion of silica, until the composition about corresponds to the formula $Al_2O_3 16SiO_2$. After that the mixture again becomes more and more refractory.

In all the circumstances here mentioned there is a substance which very frequently is found in the composition of the bodies, but which has been passed over in silence. That is the terra cotta "grog," having the same composition as the body (Chapter II., art. 42). At temperatures below that for vitrification it acts as a refractory element, but from that moment it softens again at the same time as the body, and no longer exercises any influence on the fusibility.

**146. Modifications in the Volume and the Density.** — The evaporation of the hygrometric water causes a diminution in the density of the body, because the shrinkage, if there is any, through that means is very slight, and is not made up by the increase of empty spaces. The giving off of the water of combination acts in the same manner, and we may admit that, up to about 600° to 700°, the volume of the body slightly decreases, while the density becomes continually less. But from the moment when the silicates begin to be formed the body contracts, and has a tendency to fill up the empty spaces made by the evaporation of the water and by the contraction of the organic materials. This action proceeds regularly up to the moment when, vitrification beginning, the spaces have a tendency to disappear; the body becomes impermeable, and the apparent density attains its greatest point. The shrinkage is at first constant, rather small, nearly proportional to the height of the temperature, until the latter corresponds to the firing, properly so called, of the body. After that moment, the shrinkage increases

fairly quickly, this increase becoming more rapid as the temperature for vitrification is more nearly reached.

Such are in a general way the variations of volume and density of the body while being fired. These bodies, however, in this matter present remarkable variations from one another. On the one hand, one must naturally take account of their variable proportion of water, both hygrometric and of combination. On the other hand, the shrinkage of the kaolin earths and of the clays do not take place at the same temperature; and, finally, an important amount of quartz or carbonates results in considerable variations in the volume.

In order to show these modifications in a clearer form, there have been graphically represented (Fig. 136) the variations of the total volume and those of the empty spaces for four sorts of body which are looked upon as types. But it can easily be conceived that these sketches must only be regarded as examples, without attributing to them an exactitude which, in the actual state of our knowledge, it is still impossible to give them.

The first type is that of the *kaolin earth bodies*. The total volume of the dry body, say equal to 100, diminishes very slowly and very slightly until about 800°. After that time the shrinkage grows more and more quickly up to about 1,350° to 1,375°, the temperature for burning hard porcelain, considered in pottery as the maximum that one can attain in practice. On the other hand, the volume of empty spaces contained in the dry body at first increases quickly between 50° to 130° on account of the evaporation of the hygrometric water, then remains nearly constant, and submits, between 400° and 600°, to a new rapid increase, due to the decomposition of the hydrosilicate of alumina. After having attained its height, between 600° and 800°, it diminishes, at first because of the shrinkage, and afterwards because the body, above about 1,000°, diminishes in absolute density.

This diminution is due to the formation of silicates, which are so much the less dense as they have been produced at a higher temperature. Then there occurs a very curious phenomenon, which was unexplained for a long time: the simultaneous diminution of the volume and the density of the body. The drawing shows that we must look for the explanation in the reduction of empty spaces,

which hides the inflation which is forced in the body of which the weight remains constant, while its density diminishes.

All the natural silicates—feldspars, granites, porphyry, etc.—equally undergo a diminution of density when they are heated to a temperature near that of their fusing point. Thus, for the kaolin earth body which we have been considering the absolute density (measured in the powdered body), at first about 2·4, increases in consequence of the giving off of water, to reach nearly 2·7, then it diminishes again, falling to about 2·5. As to its apparent density (the weight of the unit of volume), from 1·6 to 1·7, it at first

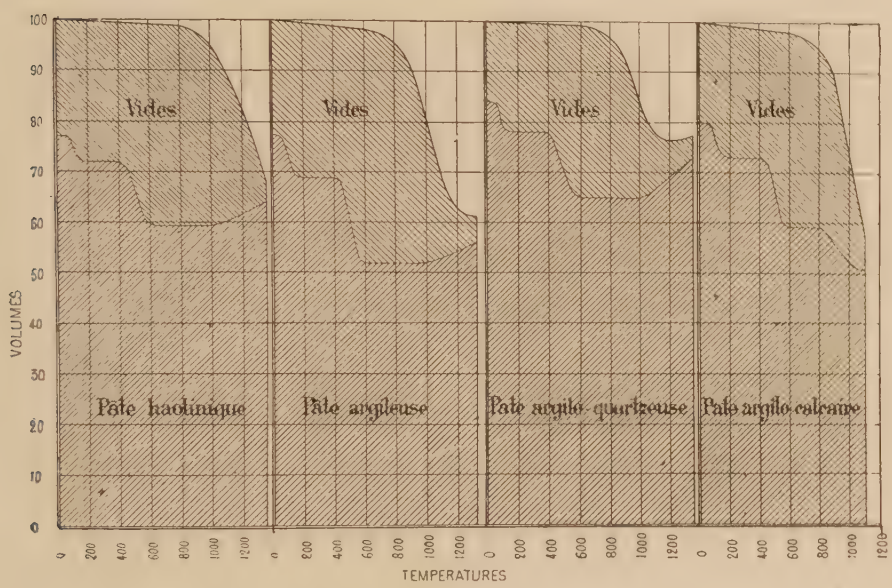



Fig. 136.—Variations of the Volume of the Bodies in Baking.

diminishes regularly until the moment of the evaporation of the water, increasing rapidly afterwards, according as the empty spaces disappear. It, however, never becomes equal to the absolute density, because, even in those bodies which are completely vitrified, there always remains a certain proportion of empty spaces.

*The clayey bodies*, very nearly pure, form the second type. This differs from the first, firstly, by the larger proportion of water, and, secondly, because the shrinkage is nearly accomplished about 1,200°, and because, after that time, the volume only diminishes very slowly. This last difference, unexplained

up to the present, is very characteristic, and thus allows us exactly to distinguish the clays from the kaolin earths.

When the bodies contain a noticeable proportion of quartz, the inflation which the latter undergoes in passing from the density 2·7 to 2·6 to the density 2·3 to 2·2, to which attention has already been drawn, is added to that of the clay, and it may be that the reduction of the empty spaces are no longer sufficient to hide it. This is the case which is represented in the third type (*clayey bodies containing quartz*), in which one sees that the volume of the body, having diminished to about 1,200°, as in the preceding case, afterwards increases. The fact can easily be noticed in practice, on very quartzose fire-bricks.

Finally, when the bodies have a sufficiently high amount of carbonates, the elimination of carbonic acid above 800° makes a third increase in empty spaces, which is represented in the fourth type (*calcareous-clayey bodies*). As these bodies are usually rather fusible, the shrinkage continues up to the fusing point, this having very likely taken place before the giving off of the carbonic acid is complete.

Thus we see, from the preceding, that for each composition of the body there correspond, during baking, different modifications in the volume and density, the importance and nature of which may be imagined, according to the four preceding examples. We repeat, finally, that these examples ought not to be taken in a rigid sense, and that the sketches only represent in an approximate manner the phenomena which have up to now been too little studied.

**147. Modifications in the Colouring.**—Among the different substances which enter into the composition of the bodies for pottery, there are only the combinations of iron and the organic materials which have colouring. It is only quite exceptionally that the oxygenised combinations of manganese, titanium and vanadium, which are also coloured, are found in them. It must be understood that this observation does not apply to the bodies into which a colouring metallic oxide is voluntarily introduced for the purpose of decoration.

Under the influence of the burning, the organic materials disappear, while the body becomes of a colour either more or

less grey when it contains oxide of manganese, and it becomes a deep greyish-blue when there is a large amount of titanic acid. As to vanadic acid, it produces yellow or green efflorescence, which will be dealt with further on. There remains the iron, which is nearly always the only colouring element in the body, and the different combinations of which give them shades varying from greenish-blue to black, from yellow to orange or red, from yellowish-brown to green. The study of the conditions under which these different combinations can be produced is one of the most complex problems in pottery.

Whatever may be the form in which iron is found in the plastic bodies, it is changed into red iron peroxide when it is heated in an oxidising atmosphere. If the body only contains a small proportion of lime or magnesia, from this fact it gets a colour varying from light yellow to yellow, then to orange, and finally to red, according to the proportion of iron oxide that it contains. An amount of 5 per cent. is sufficient to give a tint of clear red, which reaches the maximum of intensity at the proportion of 8 per cent. or 9 per cent., the colouring not being changed for a higher amount.

But as the temperature of the firing is raised the shade deepens, and has a tendency to pass into brown. In this case, the iron peroxide combines with the silica and alumina to form a double silicate, which has the colours mentioned above.

It is no longer the same when the bodies contain lime or magnesia. In this case, as long as the temperature of the oven remains below 700° or 800°, the colour due to the iron peroxide remains the same as the preceding, but if it passes this temperature, a multiple silicate is formed, yellowish when the proportion of lime or magnesia is double that of the iron oxide. In other words, these two bases neutralise the red colouring of a proportion of the iron oxide which is equal to the half of their weight. Thus, a body containing 10 per cent. of lime or magnesia and 7 per cent. of iron has about the same colour as a body that is made of alkaline earthy bases, and which contains only 2 per cent. of iron oxide. If one continues to raise the temperature, the silicates of lime and iron take a greenish-yellow tint, which becomes quite green at

the moment of fusing, as may be noticed in the glass of some bottles and in Portland cement.

When the gases of the kiln in which the burning takes place contain sulphurous fumes, these combine, in the form of sulphuric acid, with the lime of the body to form, mostly on the surface, calcium sulphate; the result is that the lime thus combined can no longer enter into the formation of the multiple silicates, and loses its property of discolouring the iron oxide. As this action is only produced on the surfaces which are exposed to the gases of the fire, it follows that they sometimes have a red colour, while the inside parts, which are more protected, keep the yellow or greenish-yellow tinge of the silicates of lime and iron.

Such are the variations of colour produced by oxide of iron when the firing is done in an oxidising atmosphere. If, on the contrary, this atmosphere is *reducing*, that is to say, if it no longer contains any oxygen and an excess of hydrogen and of carbonic oxide, the iron peroxide is changed into monoxide and gives rise to new colours.

If in small proportion, the combinations of the iron monoxide have a light bluish tinge, such as one may see in most porcelains. If the proportion increases, the colour deepens rapidly and passes into black with blue metallic reflections. The presence of a certain proportion of lime or magnesia does not alter these colours. As to the sulphurous fumes, they have no action in a reducing atmosphere, because they remain in the form of sulphurous acid.

We shall see later, *à propos* of the functions of the kilns, that the atmosphere may often be *alternately oxidising and reducing*, especially at high temperatures. In this case, the degree of oxidation of the salts of iron may be modified several times during the process of one baking. But the final colour is that which corresponds to the composition of the atmosphere at the time of cooling. If this, as nearly always is the case, is oxidising, one notices that the repeated changes in the salts of iron have the effect of diminishing the intensity of the colours.

We must, however, notice that the oxidising or reduction

of the salts of iron can only be produced in a porous paste, which allows the gases of combustion to penetrate into it. If the burning is carried to a temperature high enough to cause vitrification, or if the paste is covered with a glaze, it will keep definitely the colour corresponding to the composition of the atmosphere at the time of its vitrification or of the fusion of the glaze. This observation has an enormous importance in the manufacture of porcelain and stoneware, because it allows one to give the paste the bluish colour of the salts of the monoxide, by the reducing tendency during the principal firing, while afterwards having for it a decidedly oxidising atmosphere during the cooling.

Lastly, we must remark that, for thick or close bodies, the changes in the composition of the atmosphere can only act at the end of a certain time as far as the centre of the object. Thus, it may then happen that in certain cases the salts of iron may be, in the centre, in a state of monoxide, and, on the surface, in the form of peroxide. The contrary case, although more rare, may equally be found.

If the reducing action of the atmosphere was intense and prolonged it might cause a complete reduction of the oxides of iron, which would change it, at least partially, into metallic iron. This case is only found quite exceptionally in working. But if the cooling of the porous pastes is worked in an atmosphere charged with carburetted hydrogen, these decompose in contact with the paste when heated to red heat. The hydrogen combines more or less with the small proportion of oxygen contained in the atmosphere of the kiln, while the carbon is deposited in the pores of the paste, giving it a grey or black colour. This property is sometimes made use of to obtain black terra cottas or bluish-black ones, according as to whether there is simply a deposit of carbon, or whether this is acted upon at the same time as the reduction by the salts of iron in the form of monoxide.

If one heats it a second time to red heat in an oxidising atmosphere, the black wares thus obtained become discoloured, and take the tint that the proportion of peroxide of iron which they contain naturally gives them.

**148. Defects in the Bodies after Firing.**—The different defects that the bodies may show after baking are arranged in nine classes:

1. *The defects arising from moulding (pressing)* which have been mentioned in Chapter IV. They consist, as we have seen, in the objects getting out of shape, caused by the different density which is the result of an unequal pressure on the body during the moulding.

2. *The defects due to a bad charging of the kiln.*—These will be described in the articles relating to the process of charging the kiln.

3. *The defects arising from either a too low or a too high temperature in firing.*—For porous bodies too low a firing makes the ware too tender, slightly resistant, and badly bearing exposure to weather; for the impervious bodies vitrification remains incomplete and the ware porous. On the contrary, an excess of baking has the result of distorting the objects, then of scorifying them and then melting them.

4. *The defects arising from a too rapid heating.*—If the bodies contain hygrometric water, if they are heated too quickly there forms in the interior of their mass some aqueous vapour (steam), which may make them burst. The body once dried can be heated more rapidly, the giving off of the water of combination as well as that of the carbonic acid taking place without new difficulties occurring. But it must be remarked that it is difficult to heat equally all the parts of an object, and that, from this fact, there may occur inequalities in the shrinkage, inequalities that may cause breakages, which might be avoided by heating it sufficiently slowly and regularly.

5. *The defects arising from a too rapid cooling.*—These may be occasioned either during the cooling after burning, or by the admission of cold air coming suddenly on the ware during the burning. In the two cases it produces cracks or splits.

6. *The defects due to a wrong composition of the atmosphere of the kilns.*—This kind of defect is shown by an irregular colouring, or one different from that which is wished for. We have examined, in the preceding article, the influence that the composition, whether oxidising or reducing, of the gases of the

fire can have on this subject. We must, however, here add a word upon the harmful influence that coal smoke or the hydrocarbons may exercise. We have seen that the latter cause in the interior of the pores of the paste a deposit of carbon. In the porous wares this deposit is consumed during the period of cooling, this being nearly always oxidising; in the impervious wares it may, on the contrary, remain sealed up in the pores at the moment of vitrification, and give it a yellowish, smoky tinge that cannot be removed.

7. *The defects arising from the presence in the atmosphere of the kilns of sulphurous fumes, or of those of alkaline salts.*—In the preceding article we have seen that the sulphurous fumes, which may arise either from the fuel or from the sulphides contained in the bodies, are found in the form of sulphuric acid, if the tendency is oxidising and the temperature low enough, or of sulphurous acid, with a reducing tendency and a high temperature. In the first case the acid combines with the lime of the body and often causes spots on the parts which were more particularly exposed to the circulation of the gases. In non-calcareous pastes, and with a reducing atmosphere, these sulphurous fumes have no noxious action.

The ashes of the fuel always contain a rather large proportion of alkaline salts, which may be carried in by the draught, and fix on the surface of the ware, causing the formation of the more fusible silicates. In the beginning of the firing, when the kiln is still damp, these may also dissolve in the water that the bodies still contain, and be added to the soluble salts that the body may naturally contain.

8. *The defects arising from the soluble salts contained in the bodies.*—These defects are not due to the baking, but to the composition of the bodies; they are mentioned here, however, because they do not become clearly visible until after the burning. These soluble salts (sulphates, chlorides, silicates of lime, soda, potash and magnesia) follow partly, during the drying, the movement of the water from the centre to the surfaces, and form whitish efflorescences there. When the gases of combustion do not contain sulphurous fumes, which is the case scarcely ever except in wood firing, the result from it is simply a thinning

of the colour of the surface, these salts at the time of the full fire entering into the formation of the silicates. If, on the contrary, there are sulphurous fumes, the sulphuric acid produced unites with the bases of the soluble salts and makes sulphates, forming white spots on the ware, which are partly insoluble.

On the other hand, if the temperature of the burning is not sufficient to turn into the various silicates the soluble salts that remain in the body, these may be dissolved when the burnt wares are moistened again—by rain, for example—and they form, even after having been made several months, new efflorescences. However, these are less to be feared than the preceding, because, the salts being soluble in water, the spots produced can be taken off by simple washing.

We have seen before that the salts of vanadium contained in certain bodies also produce yellow and green efflorescences. This defect is noticed principally with clays of a lignite formation, which are very much used in North Germany. Efflorescences like the preceding ones are produced when the burnt ware is afterwards exposed to damp. There are formed first efflorescences of an intense yellow, due to vanadic acid, which, under the influence of the coaly dust of the atmosphere, take a bluish-green colour, because of the reduction of the vanadic acid into oxide of vanadium.

9. *The defects arising from the lime and magnesia contained in the bodies.*—We have already seen that when lime and magnesia are not intimately mixed in the bodies, and the temperature has not been sufficient to change them into silicates, they may remain in the form of grains of lime or caustic magnesia, which, by being hydrated afterwards in the burnt ware, would increase the volume and make the ware split. We have noticed that by plunging into water the bodies while still warm, when they come out of the kiln this defect is noticeably decreased.

The preceding enumeration of the accidents which may arise during and after baking the pottery bodies will be finished in the special examination of the manufacture of the different kinds of ware. Although each of those singly need not incur simultaneously all the defects which have just been described,

the above, nevertheless, shows the various difficulties that are found in the industrial process of firing the body.

**149. Firing of the Glazes.**—We have seen that the glazes can be applied either on a body which is simply dried, or on a body which has first been fired. In the first case the precautions which it is necessary to take in order to obtain a perfect firing of the body are sufficient to ensure that of the glaze at the same time. In the second case the operation is much easier, and one can rapidly raise the temperature to the point at which the glaze begins to vitrify. In fact, it is only from the moment at which, under the influence of sufficient heat, it is changed into glass that it attains the properties which are suitably different from those of the body.

For each composition of the glaze there is a corresponding temperature at which it begins to soften, according to the combination of its raw materials in the form of silicates and borates. Then, becoming more fluid, it spreads equally over the surface of the body in the form of a viscous, adhesive layer. If the temperature continues to rise, its fluidity would become sufficient to destroy its adhesion to the body, and it would run towards the lowest parts, and would afterwards end in being volatilised.

We see then that the temperature for firing the glazes is confined between very narrow limits; also, that it is necessary to give them such a physical structure that the liquefaction shall not take place suddenly, but be preceded by a fairly long period of pasty moistness. When the vitreous layer is spread uniformly, the temperature is kept up for a period of time which varies with the nature of the ware, then it is let down regularly and slowly enough to prevent the accidents which were mentioned in the preceding article.

The defects which the glazes may present after being baked are divided into four classes:—

1. *The defects arising from the non-adhesion of the glaze.*—We have already seen that the glaze may detach itself from the body before firing, when it is not sufficiently plastic and becomes powdery in drying. It may equally occur that the surface of the body is too compact, or may even be covered with

dust or be oily, in which case the glaze cannot very well adhere to it. The result after firing is fissures in the vitreous layer, which seems to contract.

2. *The defects arising from the body being too absorbent.*—Contrarily to what takes place in the preceding case, the body may be too absorbent, the glaze when vitrified penetrates the pores of it and may completely disappear in them. It is curious that the same effect may be observed fairly often when the ware is put in the kiln by the side of pieces made of porous bodies which are not glazed, as, for example, the saggers which are used in charging or for the walls of the kiln. In this case there is a more intense volatilisation of the glaze which is carried on to the unglazed bodies. One says then that the glaze *is sucked in* by the body.

3. *The defects which are the result of a too low or a too high temperature in burning.*—In the first case the vitrification is incomplete, and the glaze has the appearance which is characterised by the name of *eggshell*. In the second case the too fluid glaze runs towards the lower parts of the ware, leaving the others bare. This defect of *trickling* is also produced when the glaze is too thick for it to be entirely kept up by the adhesion of the body. In certain cases a too high temperature can also cause a boiling of the glaze, which then on cooling is filled with *bubbles* or *blisters*.

4. *Defects in the composition of the body or of the glaze.*—In this case the glaze can also contain *bubbles* or be dotted with a crowd of little blackish points. The cause of this defect is either in a gaseous decomposition of the glaze (the giving off of carbonic acid, oxygen, etc.), or in a chemical reaction which is produced by the elements of the body with those of the glaze.

The study of the defects in the glazes will also be completed in the special examination of the different sorts of pottery.

**150. Agreement between the Bodies and the Glazes.** — So far, there has only been question of the burning of the bodies and glazes taken separately. We must now study the conditions between them which must be fulfilled to give a ware without any defects.

We have already observed that if the burning is to be done

in a single operation, it is necessary that there be *an agreement between the temperatures for firing* the body and the glaze. This agreement is generally easy enough to manage, by varying, either in one or the other or even in the two simultaneously, the proportion of the refractory elements or of the fluxes. This problem no longer exists when the burning is done in two operations, the first intended to fire the body and the second, at a lower temperature, vitrifying the glaze.

However, no matter what process of firing is adopted, from the moment when the glaze is spread as a glass on the surface of the body, these two elements of the ware become united, and it is necessary that while cooling they should contract equally. Like all solid bodies, the bodies when fired, and the glazes expand under the influence of heat, and return to their original size when cooled. One can understand then that it is necessary for them to have during cooling *an agreement between the contraction of the body and that of the glaze.*

If the glaze contract more than the body, it will often be subjected to a tension which may cause its rupture, either in connection with the cooling, or later by the influence of an external cause (concussion, heating, etc.). This breaking takes place in the form of more or less numerous cracks, either more or less wide apart, or larger or smaller, called by the name of crazing. The nearer together or the more numerous these are, the greater the antagonism between the body and the glaze. Sometimes, when the glaze is very thick, this defect may become serious enough to cause the body itself to break.

If, on the contrary, the glaze contracts less than the body, it is found compressed, and if this compression passes the limit of its elasticity, it breaks, forming chips, which are detached from the body, sometimes taking portions of it with them. This defect, which is opposed to crackling, is called by the name of *scaling.*

The problem of the agreement between the contraction of the body and that of the glaze is the most difficult one that is met with in pottery. It can only be solved by a series of trials, and one can understand the difficulties, often insurmountable,

which beset the ancient potters, who did not know the exact compositions given by chemical analysis, and who were ignorant even of the cause of their failures.

This, then, is the quickest method of solving the problem. We begin by determining exactly the chemical composition of the paste and the glaze, then proceed to firing trial pieces.

If these show crazing, the composition of the glaze is modified by diminishing the proportion of alkali, and increasing that of the earthy alkaline bases of the silica or of the boracic acid. It is, in fact, the alkalies, potash and soda, which make the compounds that expand the most; the oxide of lead occupies a middle place, while the compounds of the alkaline earth bases, alumina, lime and magnesia, have the least expansion. On the other hand, the monosilicates have a greater expansion than the bisilicates. Boracic acid gives compounds which act like the bisilicates.

The action of the colouring oxides will be examined in the following chapter, which treats of the decoration of the ware.

When, on the contrary, the trial pieces are scaled, we modifiy in the opposite way the composition of the glaze.

Generally, after some failures, the desired result is arrived at. If, however, such is not the case, then the composition of the body must be modified, and then begins a new series of experiments.

When crackling occurs, these are the modifications that can be tried with the body :—

1. Increase the proportion of silica.

2. Grind it more finely.

3. In the non-vitrified bodies increase the amount of the fluxes.

4. In the vitrified bodies, on the contrary, diminish the amount.

5. In the bodies containing ball clay and china clay increase the proportion of ball clay and diminish that of the china clay.

If, on the contrary, there is scaling, naturally the reverse modifications are made.

Silica has a much greater expansion than clay, also its mixture in a body results in diminishing crazing and increasing scaling. This action is so much the more noticeable as its

grains are finer. It follows that we can diminish the crazing by grinding the silica more finely, or, on the contrary, diminish the scaling by mixing it in the form of coarser grains.

As to the fluxes, they act upon the temperature for firing the body. In the non-vitrified bodies the expansion goes on rapidly increasing as one raises the temperature of the burning. The result is that in vitrifying a glaze on three specimens of the same body, one slightly, the second medium, and the third very highly fired, if it agrees with the second, the first will have crazes and the third will be scaled. In this case the increase in the amount of fluxes acts like the raising of the temperature by diminishing the crazing and increasing the scaling. It is not the same for the vitrified bodies in which the expansion diminishes; on the contrary, from the moment when vitrification begins, they change more and more into a vitreous production. In this case the increase of fluxes causes crazing and diminishes scaling. The bodies which are not vitrified, but are rich in silica, act in the same way; one notices, in fact, that their expansion, after having reached the maximum, begins to diminish with the raising of the temperature. This fact can be explained by the progressive change, under the influence of heat, of silica with a density of 2·7 to 2·6 into silica with a density of 2·3 to 2·2, the first having a greater expansion than the second.

The foregoing observations, while showing the line to be followed in solving the problem of the agreement of the bodies and glazes, equally show the difficulties it presents, as well as the perseverance and professional skill that it needs on the part of the potters.

The exact measure of the contractions, or rather of the expansions of the bodies and glazes, has been the aim of long and minute experiments by MM. Le Chatelier and Damour. By means of very precise and ingenious apparatus, these clever experimentalists have proved that the co-efficient of expansion varied from 0·000002 to 0·000007 for an increase in the temperature of one degree. Unfortunately, these researches are only of theoretical interest, because by determining separately the expansions of the body and the glaze, no account is taken of the action they have on one another; an action

which, especially for stoneware and porcelain, may be sufficiently important to do away with all the value of the figures thus obtained. Besides, there is hardly any need to remark that these experiments would not in any degree replace practical researches, which are neither simplified nor shortened by them.

151. **Experiments in Fusibility and in Firing.**—It is seen by the preceding that the trials in burning are of considerable importance, and that one may need to make a great number before undertaking a new industrial manufacture. Hence it is necessary to possess a test kiln, which will allow of quickly getting a high temperature, and the arrangement of which can be easily

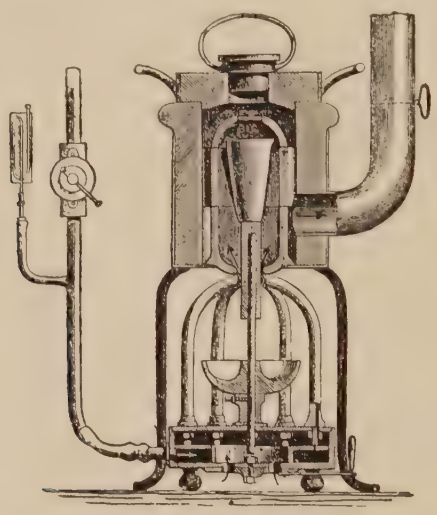


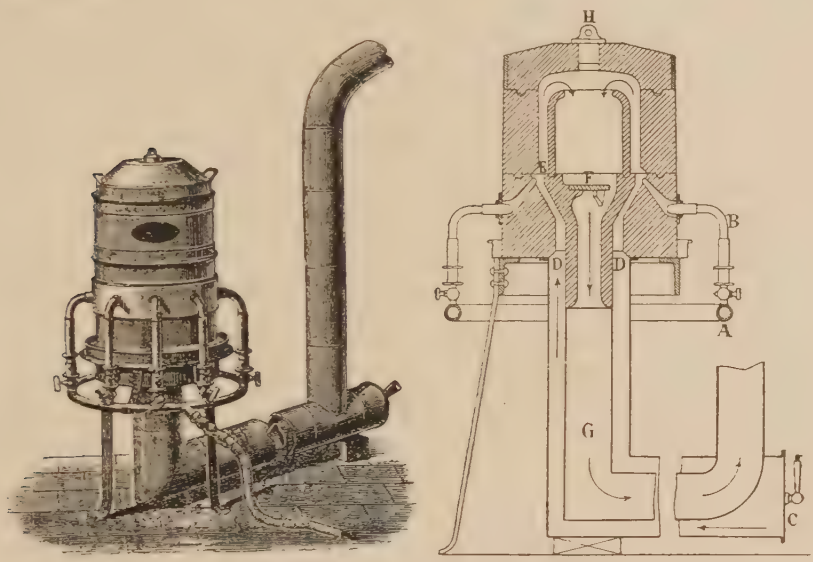
Fig. 137.—Trial Kiln.

modified so as to give at pleasure oxidising, neutral, or reducing atmosphere.

The fuel employed in test kilns is charcoal or illuminating gas. When one uses the former, and for a temperature not needing to pass 1,000°, one may be content with one of the reverberatory furnaces used in chemical laboratories. For higher temperatures one must have recourse to the use of a blast (or one with bellows). One can, with this object in view, use an apparatus which is composed of two iron-plate boxes, leaving a space between them of 2 to 3 centimetres, into which the air is pumped, the pressure of which is shown by a manometer tube. The inner box is furnished with fireclay parts, through which are arranged

small openings, allowing the passage of the pumped air. The trial pieces are put towards the middle of the central space by placing them on a fireclay support and protecting them, if necessary, from contact with the charcoal by another thin piece of fire-brick. After having put some embers at the bottom of the kiln it is completely filled with charcoal, and the bellows are started, at first gently, then more and more quickly, constantly adding more fuel.

This kiln is difficult to regulate, and it is scarcely suitable, except for trials in terra cotta or fireclay, for the sake of determining their fusibility. For the trials on vitreous ware and of glazes, satisfactory results are only obtained by heating with gas.




FIGS. 138 pus 139.—Test Kiln.

Fig. 137 shows an apparatus designed by M. Perrot (built by M. Wiesnegg), which fairly easily gives a temperature of 1,200°. The gas, the pressure of which is measured by a manometer, is let in by a lower ring, from which it passes by a series of tube spouts placed circularly, by drawing a certain quantity of air through which one can regulate the volume by means of a disc worked by a crank. The flames which spring out at the extremity of the spouts penetrate to the centre of the lower part of the kiln, to pass round the crucible or the piece to be heated, then descend again along the outside

walls of the kiln and escape by the chimney. This kiln is constructed with six, nine, twelve, and even twenty spouts.

One really prefers the kiln shown in Figs. 138 and 139, built by M. Wiesnegg, which easily allows the temperature for burning hard porcelain to be obtained. The gas is led in by a series of spouts, B, through a circular pipe, A, while the air enters at C into an horizontal plate-iron tube, then vertically, and penetrates at D into the kiln. The combustion takes place at E, and the flames rise first, to come down afterwards round the pieces to be burnt, which are placed upon a little table, F. Thence they continue to descend, and the products of combustion enter the pipe G, where they warm the air, to escape afterwards through a chimney. The management of this kiln is easily regulated by opening the little plug H, and seeing whether air goes in or flames come out.

Trials as to fusibility are worked with pieces of terra cotta, or by making little bricks, or better still, little pyramids. For the trials of impervious ware, or of glazes, little plaques are used, some millimetres thick and about 15 to 20 centimetres square. It is always wise to try on two or three pieces alike, because of accidents in firing which it is not always easy to avoid. The measuring the temperature is done by means of pyrometers, as will be described further on *à propos* of the working of the kilns.

## § 2. Description of the Kilns.

152. **General Remarks on Kilns.**—All kilns are for the double purpose of producing and utilising heat. The *production of heat* is by means of the firehole, due to the apparatus for forming draught. Under the name of *firehole* one includes that part of the arrangements used for introducing the fuel into the kiln, to mix it with the air and thus insure its combustion. The *draught apparatus* is for insuring the introduction of the air, and for creating in the interior of the kiln the circulation of the gases and flames. The *utilisation* of the heat is done in one or more *burning spaces*, intended for bringing the flames or hot gases into contact with the objects, or with the receptacles

in which the objects have been placed, and which constitute the kiln properly so called.

To these three essential parts must sometimes be added a fourth at discretion, the *receiver*, which is intended to utilise, in an indirect way, a part of the heat which has not been used for the direct heating of the ware.

The particular arrangements, and the mode of construction of these different parts of the kilns depend on the fuel used, on the temperature to be obtained, and on the special conditions of burning of the different ceramic productions. These will be examined closely in the chapters set aside for the manufacture of them; there will at present be only a description of the general arrangements of the kilns—the firehole, draught apparatus, burning spaces, or kilns properly so called, receivers and the method of construction.

The kilns at present used in the ceramic industries are of very different types in all ways. This diversity is partly justified by the variety of wares and by the differences in the temperatures for burning them; but by examining the numerous systems of kilns in use from the point of view of production and of the rational utilising of heat, it is easy to see that a number of them should be absolutely condemned. One is even often surprised to meet, by the side of mechanical contrivances which are perfect for the preparation and shaping of the bodies, with kilns which are absolutely illogical, of uncertain working, of a deplorable yield. One may also often see types of kilns which are absolutely defective being perpetuated in certain localities, or in special branches of the ceramic industry.

The cause of this peculiarity must be sought in the ancient traditions of the potter. Pottery has been for a long time one of the rare industries using high temperatures, and the only one which has been obliged to utilise them for an operation requiring so much exactness and care as the firing of the ware needs. The result was that the ancient potters, not being able to find either help or advice from outside, have looked upon the construction of the kilns as a professional secret, of the same standard as the composition of their bodies or their enamels.

The progress of mechanics has taken them unawares, nor

when they have needed to modify their manual tools have they turned to the mechanicians. On the contrary, the discoveries of chemistry, as those of industrial physics in their application to ceramics, have left them too often incredulous or distrustful; they have been obstinate in preserving their processes of empirical mixtures and their pretended secrets of firing.

During this time the science of the production and utilisation of heat has made by their side, unknown to them, considerable progress. Also potters cannot be too strongly advised to consult specialists for the construction of the kilns, in the same way as they order their machines from engineers, and to give up secrets in firing, which are nearly always merely a name hiding only an inveterate routine.

However, from the numerous types of kilns, which are at present too many, several of which ought to be given up, we must not, in conclusion, fall into the opposite extreme, that all pottery kilns ought to be constructed according to a certain number of uniform models. After having chosen a type of kiln, we must, on the contrary, study all the arrangements of it, not only for the special manufacture that one has in view, but also taking account of the nature of the fuel, the variable properties of the bodies and glazes, the materials in the construction and the general necessities of the manufacture. It is only by satisfying in some measure these multiple conditions, even sometimes contradictory ones, that one can obtain a kiln which is satisfactory for the double requirements of working and economy.

### (*a*) *The Fireplaces.*

**153. Fuel.**—As in all other industries, the first fuel that was used in pottery was wood; it is only in the course of this century that it has been almost entirely replaced by coal. Wood, however, is still used because of its low price in certain wooded districts; besides, it has real advantages in firing wares for which the expense of fuel is relatively small in regard to their value. For local reasons, lignite is also used as well as peat, and occasionally vegetable materials, grass, straw, mineral oils and natural gases.

On account of the distance which there always is between the firehole and the goods to be fired, one can only use flaming

fuel, the production of flames necessarily being as much more intense the greater the distance is. It is only in an exceptional case, which will be mentioned further on, and, on the other hand, during the commencement of the burning, when it only is needed to warm the atmosphere of the kilns so as to evaporate the water contained in the ware, that one can make use of poor fuel.

The same as in all other industries, dry fuels are preferable which contain very little cinder, and those are avoided which cling together or become exhausted by the action of heat. When it is needed to obtain high temperatures, it is no longer possible to use anything but wood of good quality, in the form of logs, or fat coal, or open-burning coal, which is fairly pure. By first changing the fuel into gas in the gas works, however, relatively inferior fuel may be used.

The burning of glazes especially needs fuels which give off very little smoke and contain only a small proportion of sulphurous materials.

Special works are generally very full of theories on the combustion, and of directions as to the composition of the calorific power of fuels. One must, however, accept their figures with caution, because they are made out from mediums and from specimens chosen with care. It is scarcely interesting, from an industrial point of view, to follow them in this direction, and we will content ourselves with giving on each kind of fuel some practical suggestions.

*Wood.*—Wood may be employed in the form of logs, faggots or sawdust. We have seen that in high temperatures logs can only be used of such regular sizes as are suitable to the fireplace. By using special arrangements, we can make use of faggots for the baking of ordinary ware, and to obtain a moderate temperature. As to sawdust, it can only be used mixed with coal, either for direct heating or for gas generators. Up to the present, wood gas has not been used for pottery, and it seems scarcely probable that it will ever become advantageous.

From the heating point of view, the hard are distinguished from the light woods. The former are oak, beech, elm, ash; the latter, birch, fir, pine, larch, poplar, aspen. The hard woods, having a weight per cubic foot of 28 to 25 lb., give more heat,

but produce a short flame. The soft woods, the weight of which varies from 22 to 19 lb., are less heat-giving, but, on the other hand, give off long flames, which are usually better for the burning of pottery goods. Yet the softest kinds are unsuitable for the production of high temperatures. Besides, certain resinous essences are to be feared, as these would produce fumes that might alter the glazes. Generally, for burning the bodies, fir, pine and larch are preferred, and for burning the glazes, birch, sometimes beech or ash.

*Coal.*—Coal is classed under five heads, according to the proportion in it of volatile materials, and the manner in which they behave during combustion :—

1. *Anthracite* and sandy coals, with a short flame, containing from 5 to 11 per cent. of volatile materials, giving a pulverulent coke, and weighing from 56 to 53 lb. per cubic foot. These coals can only be employed alone in gas generators and for the production of medium temperatures.

2. *Open-burning coals*, containing from 11 to 13 per cent. of volatile materials, giving a compact coke which is fairly hard, weighing from 53 to 50 lb. per cubic foot. They can only be used directly in pottery when the combustion is done in the midst of the objects to be burnt. In other cases, their use is the same as the preceding, although they may be rather preferable to them.

3. *Fat coals*, called smithy coal or blacksmith's coal, containing from 13 to 15 per cent. of volatile materials, giving a more or less swelled up coke, weighing from 50 to 46·5 lb. per cubic foot. They can only be used in the form of a mixture with close-burning coal (sandy coal) on account of their tendency to cake.

4. *Gas coals*, containing from 15 to 20 per cent. of volatile materials, giving a coke which easily falls in pieces, weighing 46·5 to 43·5 lb. per cubic foot. These coals are specially suitable, when they do not cake, for the heating of kilns needing long flames and a high temperature.

5. *Sandy coals*, with long flames, containing more than 20 per cent. of volatile materials, giving a sandy non-caked coke, and weighing less than 43·5 lb. per cubic foot. They are used

for baking pottery goods, but give lower temperatures than the preceding ones.

In the compositions which have just been mentioned there is no account taken of the proportion of clinkers, which is very rarely below 5 per cent. and may reach as much as 25 and 30 per cent.; the medium is from 7 to 15 per cent. The clinkers do not only diminish the calorific power of the coal, but they also spoil the combustion by filling up the gratings, forming iron dross, needing frequent cleanings, which always means stopping or slackening the burning, and which even, under certain circumstances, may spoil the success of it.

Generally, it is advisable, for the manufacture of fine ware and for obtaining high temperatures, to take the dearer coals, and those of the best quality.

In these cases it would also be better to use gas generators, but noticing that even when changing coal into gas, it is necessary, for the kilns that require a high temperature, to use fuel which contains a sufficiently large proportion of volatile materials.

For the ware of less value, baking at a lower temperature, one is often inclined to make use of coals of inferior quality, but it is only by industrial trials that one can, in each special case, arrive at a solution as to which is really the most economical.

*Coke* is a very good fuel at the commencement of the burning, because of its regular combustion, but it can no longer be used when it is necessary to produce flames. At most one might sometimes make use of it when mixed with fat coal.

*Lignites* of good quality are suitable for firing pottery at moderate temperatures; ligneous lignites, the same as peats, can scarcely be used except for the manufacture of ordinary terra cottas in recuperatory kilns. It is essential that they should be as dry as possible.

*Grasses and straw* have been used in the absence of other fuels for the burning of common bricks. *Natural gases* have been made use of in Pennsylvania, which is the only place where they are the object of regular mining. In the same way

natural oils have been employed in the United States and in the Caucasus; it is not likely that the use of them will extend outside the countries where they are produced. Lastly, they have sometimes made use of tan, of the hard crust of the olives, of camel's dung, etc.

The value of a fuel is often considered to be proportional to its calorific power, that is to say, to the number of degrees of heat given off by the combustion of a pound. This amount it is always interesting to know, but it would not be sufficient in industrial practice, because count must also be taken of other properties. Really, for a given application, the effective value of a fuel can only be determined by an industrial trial, in which one must try to suit the fireholes to the new fuel, only taking into consideration in a moderate way the advice of the firemen, who are always opposed to any modification whatever. If one is afraid that the use of an unknown fuel will spoil the burning, it is easy to mix it in larger and larger quantities with that to which one is accustomed.

It is useful, however, before every industrial trial, especially for coals, to determine the proportion of ash, and of the principal volatile materials at a good red heat, which operations may easily be done in any kind of crucible, and which it is good to renew, from time to time, in the course of a delivery.

**154. Classification of the Fireplaces.**—The combustion can be done in pottery kilns by means of four arrangements of different fireplaces:—

1. Combustion in the midst of the goods to be burnt, these latter filling in part the place of the fire hearths.

2. Combustion in fireplaces with a grate.

3. Combustion in furnace fireplaces.

4. The changing of fuel into gas in the gas-generating fireplaces, and the combustion of the gas thus produced in the burning place.

*The combustion in the midst of the ware* is only used in the manufacture of terra cottas, which do not fear the contact of ashes, nor of the fuel while alight. This method of heating is, in theory, the most economical, because it immediately utilises the heat; also, when the circumstances are suitable, it ought to

be preferable to all others. One can see that, thanks to the special process of charging the kilns, one can also make use of it for wares that do not fear the contact of the ashes, or the direct action of the flames.

The fuels which can be employed are wood in the form of logs or faggots, rather close-burning coal, or open-burning coal, lignite and turf.

*Combustion in fireplaces with grates* is suitable for burning all pottery wares. The fuel is spread on the surface of the grate so as to form a uniform layer, letting sufficient air pass to insure complete combustion. These fireplaces are very good for the production of low or medium temperatures, and especially for the first period of the burning called the slow-firing. The flame they give is of medium length; one can lengthen it by increasing the thickness of the layer, but then there is a risk of having incomplete combustion. For high temperatures the use of them is inconvenient; they get dirty, are difficult to clean, and the grates quickly wear out.

The latter can be of metal or of fireclay ware. All kinds of fuel can be used except those that are in powder.

The *combustion in furnace fireplaces* is rather peculiar to the pottery industry. The fuel is used in a comparatively thick layer, the fireplaces can be with or without a grating; these are ordinarily two zones, one in which takes place the distillation of the fuel, and the other in which are consumed the embers or the coke formed. They usually have several entrances for air, which are regulated at will. The flames produced are long, the shape of the fireplace can easily be modified, the cleansing does not present any particular difficulty. These furnaces are very suitable for the production of high temperatures, but the slow firing is difficult to regulate in them, and often requires special arrangements.

The fuels used are wood in logs and open-burning coal with a long flame.

Gas generators are special fireplaces, independent of the furnaces, in which the fuels are changed into gases, which, by means of a system of channels, are led into the kilns, where they catch fire on coming out of the burners and on contact

with the air. The management of the kilns heated thus by gas is remarkably easy; it is suitable for all methods of working and for all temperatures. It must, however, be noticed that the changing into gas involves naturally a loss of heat, which must be compensated by other advantages, without which this method of heating becomes more troublesome.

The gas generators used until lately have usually left something to be desired from the point of view of regularity and of cleansing, the latter being often very difficult. It is to these causes that must be attributed certain failures in heating by gas. The gas generators with blowers, which are more recent, partly remedy these inconveniences, but they have a drawback in being rather costly.

The only fuels used are coal, lignite, and sometimes coke.

The general arrangements of the different types of fireplaces having been thus shortly described, we will proceed to study with more details the heating by wood and also by coal in the fireplaces with gratings, the furnace fireplaces and the gas generators. As to the other fuels, with a very restricted and very special application, some remarks on the subject of them will be found in the second part of this work, *à propos* of the special manufactures in which they have been used.

**155. Heating by Wood.**—We have seen that the combustion of wood can be done in the midst of the goods when the latter are not injured by the contact of the ashes, which are easily carried about by the draught. This kind of heating usually does not present any other difficulty than that which results from the putting of the wood into the kiln, a charging which has to be frequently done, and which causes the entrance of cold air, thus causing a loss of heat, and often loss in the goods. These defects are felt especially when faggots are used. In order to remedy this, it is advisable to lengthen outwardly the openings for charging in the shape of tunnels (Fig. 140), closed by a sheet-iron plate suspended at the upper part, and in these is burning a certain quantity of wood which warms the amount of air drawn in by the draught while the charging is taking place. This arrangement, which is used especially for faggot fuel, is also applicable to the intermittent kilns just as well as to the

continuous kilns. When the wood is in the form of logs, it can be introduced into the latter kilns by openings arranged in the dome, as we shall see further on, *à propos* of heating by coal.

Blocks of wood can just as well be burnt in the fireplaces with gratings; the latter may be of metal, but it is preferable, on account of the heat to which they are exposed, to make them of fireclay materials. Fig. 141 shows an arrangement of

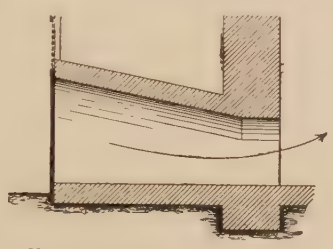


Fig. 140.—Heating by Wood.

this kind. In the same way as in the preceding, it is wise to prolong the hearth beyond the front of the kiln. The wood is put in by an upper passage, the dome of which, pierced with one opening, is placed immediately underneath the kiln and carries the objects to be burnt. The air enters by a lower passage which forms an ashpit and leads into the upper

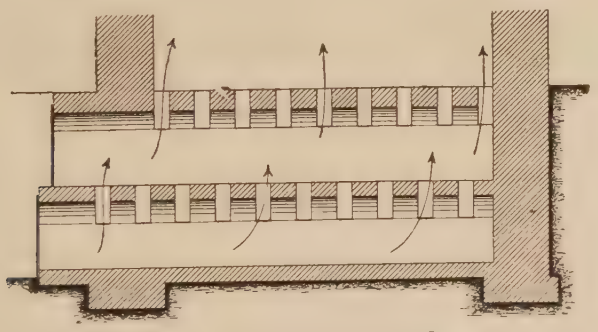


Fig. 141.—Heating by Wood.

passage by the openings which are arranged regularly in the dome of it, not opposite those of the first one. A part of the embers fall into this ashpit and are consumed there while heating the air. This arrangement is specially applicable to kilns with an upward draught; it can easily be modified according to necessity.

For the production of high temperatures fireholes are used, to

which very many different shapes are given. The type represented in Fig. 142 gives good results, provided logs of the same length are used. These are put in in a heap through the upper opening of the fireplace and rest on two brickwork projections. The combustion takes place by the air passing between the logs, and the flames follow the direction shown by the arrows. The embers which fall to the bottom of the fireplace help the burning, thanks to the introduction of air through the door of the ashpit. An opening arranged in the wall of the front of the fireplace allows, if necessary, of the entrance of some extra air. This type of fireplace is joined side by side with the kilns, it gives very long flames and is suitable for all kinds of work. For slow firing the logs must be replaced by faggots, or even the upper opening may be closed with a damper, making a moderate heat only through the ashpit.

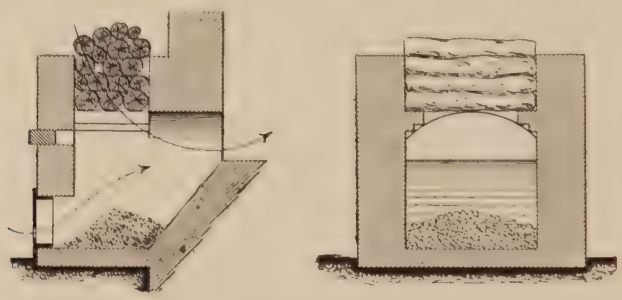


Fig. 142.—Wood Fireplace.

**156. Heating by Coal with Fireplaces Formed of the Ware.**—Ordinary bricks can be burned by alternating a layer of bricks and one of fuel, as is done for lime burning or for cement, and also in blast furnaces. This method, which is specially used in Flanders, will be described, on account of its very special characteristics, in the paragraph devoted to the manufacture of bricks (art. 206). The contact of the fuel with the ware, and the necessity of preventing the formation of cakes of coke, make it preferable in this case, and as a solitary exception, to use rather sandy coal.

In certain kilns with an horizontal draught the fuel can be equally well cast directly on to the ware, these, which consist only of solid or hollow bricks, having been placed in the bottom

in such a way as to form a species of firehole with steps. The two arrangements generally used are shown in Fig. 143.

In A these fireholes are a kind of well, in which, at intervals, are found bricks as projections, which keep back part of the fuel thrown in at the upper opening, this being provided with a tube and a cover.

In B the charging is arranged in such a way as to leave a bay, in which the bricks are put, making regular projections, and cross the empty space, forming stages of steps. The fuel, somewhat small, which is kept up by each of these stages, burns there in the current of warm air, which horizontally crosses the kiln. The charging ought to be done in small quantities,

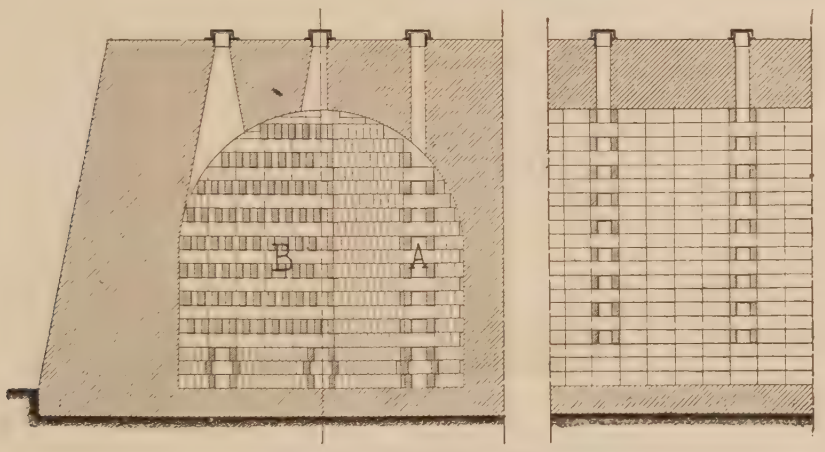



Fig. 143.—Heating by Coal.

frequently, and at regular intervals. The separation between the two openings for charging varies from 27·56 in. to 59·05 in. As the ashes cannot soil any of the objects except those forming the well or the bays, the more delicate wares, such as tiles, paving tiles, etc., can be put between them.

The firing is done with rather small open-burning coal. As has already been said, wood fuel can just as well be used, but in that case the bricks that project are done away with.

**157. Heating by Coal with Fireplaces with Gratings.**—The fireplaces with gratings for heating by coal can either be placed below or by the side of the kiln. In the first case they are narrow, but very long. Fig. 144 shows an arrangement of this kind, in which the grate is placed on a level with the lower

bed of the kiln. The fireplace could equally well be covered with a dome, perforated, as shown in Fig. 141. The charging of the fuel is done by a door placed at one end. In certain kilns this door is left out, and the coal is thrown on to the grate by one or more openings arranged in the top of the kiln, somewhat similar to those shown in Fig. 143, the air always being brought in through the ashpit.

When, on the contrary, the fires are by the side, they take the square form. It is then generally preferable to make the grate inclined, so as to be able to push the coke more easily towards the back and to put the fresh fuel near the charging door, as is shown in Fig. 145.

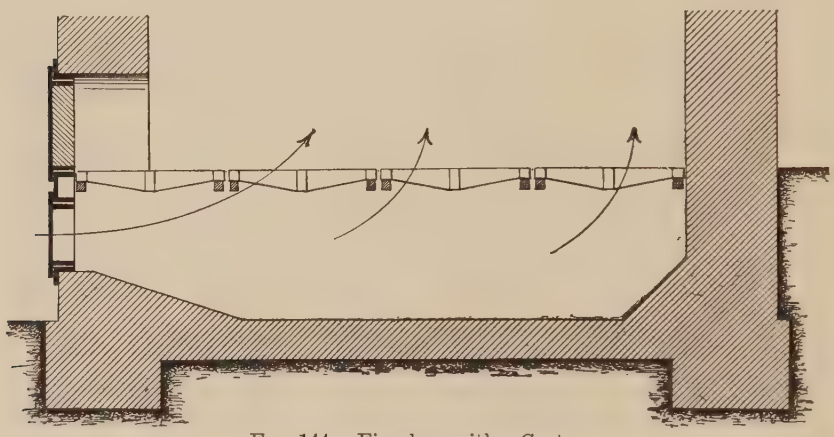


Fig. 144.—Fireplace with a Grate.

The gratings are always metal, the size of them when empty depends on the nature of the fuel. Formerly one used square or rectangular iron grids, instead of separate cast-iron bars. Now, one prefers to join several bars into the same piece of cast-iron, so as to be able to have them thinner and thus better to divide the entrance of the air. At the same time they are made higher. The immerged grates by M. Michel Perret are seldom used in pottery, where, except for gas generators, the putting of water in the ashpit is usually avoided. It is the same with the grates to which one gives an oscillating movement, so as to shake off the dross, because, the heating being intermittent, it is usually possible, with good fuel, to prevent the blocking up of the grate during the burning.

However, the grate shown in Fig. 146 (Wagner) might, for certain of the more difficult kinds of fuel, give excellent results. The fronts of the fireplaces ought to be very solidly

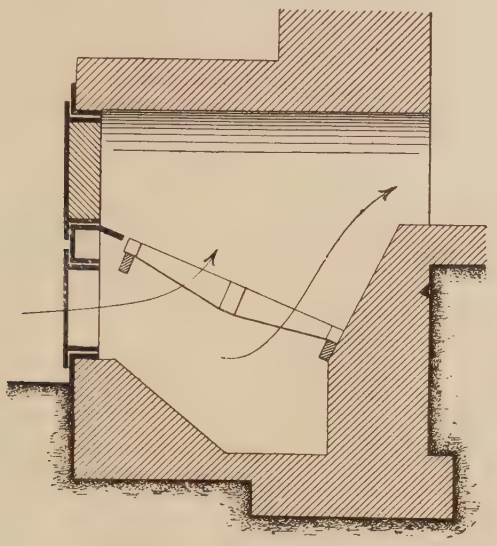


Fig. 145.—Fireplace with a Grate.

built, otherwise it is better to leave them out altogether, and to replace them by plates of sheet-iron simply put against the doors for charging and of the ashpit.

**158. Heating by Coal with Furnace Fireplaces.**—The first

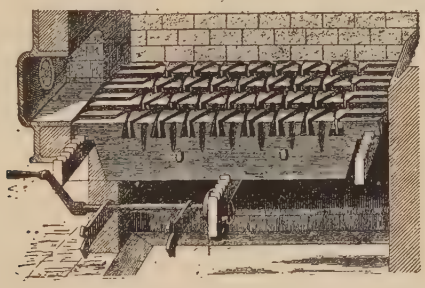
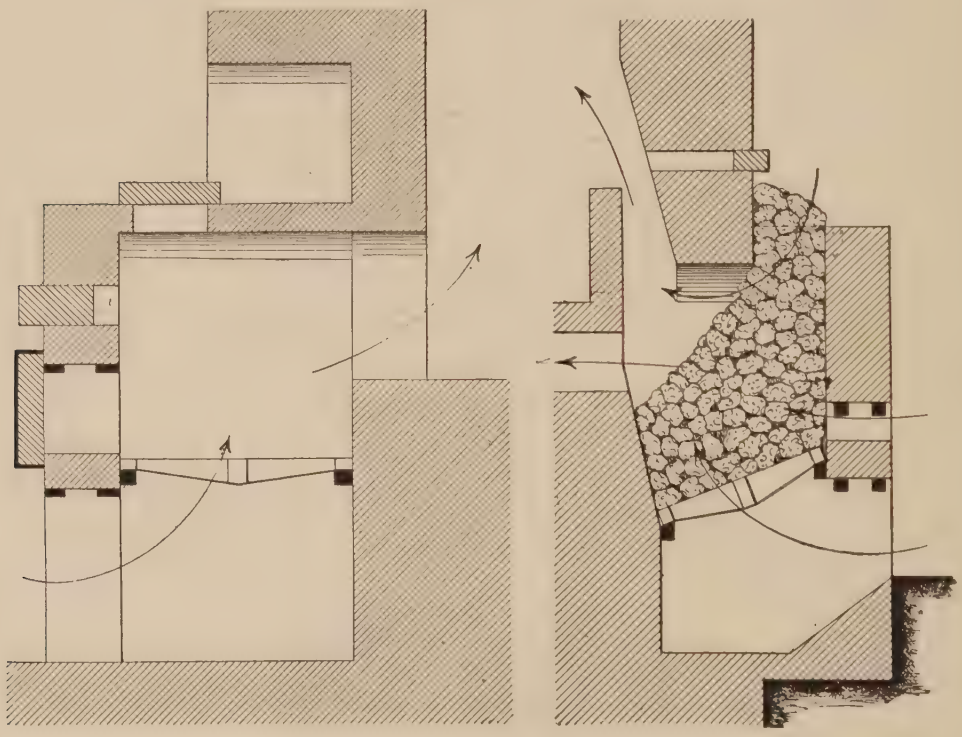


Fig. 146.—Fireplace with a Grate.

furnace fireplaces were taken from the fireplaces with grates, in which, by means of an upper opening for charging, one could introduce a thicker layer of fuel. Fig. 147 shows an arrangement of this kind. The door at the side on the level of the grate is only used for cleansing purposes, the ash-

pit is more or less closed by means of a sheet of iron, and, lastly, an opening placed between the opening for charging and the door for cleansing allows of an extra supply of air. This furnace is very suitable for slow firing, but, in working the full firing, the fresh fuel falling on the burning coke causes irregularities in the action.

The firehole shown in Fig. 148 is for continuous charging. The fresh fuel distils in the upper part, while the coke is burnt



Figs. 147 and 148.—Furnace Fireplaces.

by the air coming in through the opening for cleansing and through the grating. The flames go out of the fireplace by two openings, one vertical, the other horizontal, but this arrangement is a detail, and only one exit, as in the preceding example, would be sufficient.

In the new kilns, one gets further and further away from the form of the grating fireplaces, to approach that of the gas generators. Fig. 149 shows a firehole set up from this idea. The grating, very much sloped, is suspended at its upper part,

and leaves at its lower end, between it and the brickwork, a space through which the ashes and rubbish accumulate in the ashpit, from which it is easy to take them out. As in the preceding case, the fuel distils in the upper part, and the coke formed burns in contact with the air which comes through the grate. There is an extra supply coming in on each side, the air having been first warmed by circulating through channels placed in the side walls of the furnace. The charging opening is usually shut, the fuel contained in the sloping channel of brickwork serving for feeding it during the interval between two charges. The cleansing is very easily done, almost automatically, by the descending of the fuel; besides, for this

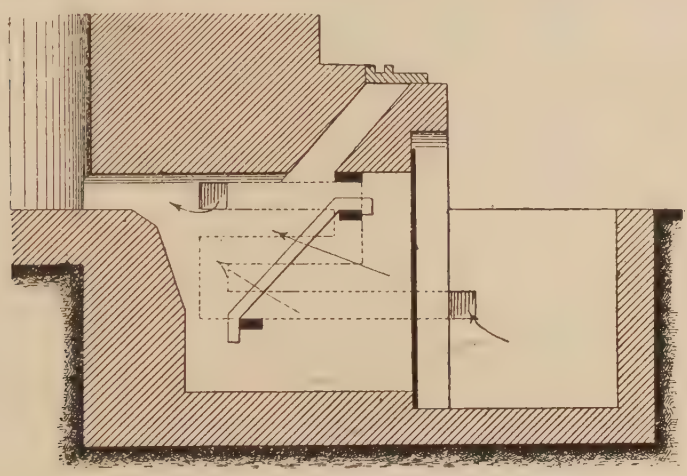


Fig. 149.—Kiln Fireplace.

purpose a rake can be passed between the bars. This furnace gives very good results for the full firing, and allows of fuel being used which makes a good deal of rubbish, but does not lend itself to a progressive carrying out of a slow firing.

To remedy this inconvenience, it has been sought to reduce the section of the grate during the first portion of the burning. Among the various solutions which have been proposed, it is only necessary to mention one, which consists in putting on the sloping grate a fireclay diaphragm, which is pushed to the end while the slow firing is going on, and which is drawn gradually off when it is desired to increase the intensity of the firing.

The furnace shown in Fig. 150 (E. Bourry), also seems to solve this question, although theoretically in a less complete manner. The grate is formed in one part vertical and in one part sloping. During the slow firing the former is closed by means of fire-brick dampers, and the fuel forms a reduced layer, A. Afterwards the openings of the vertical grate are opened in succession, to lead to the full firing with a thick layer, B, and a large amount of air. As in the preceding furnaces,

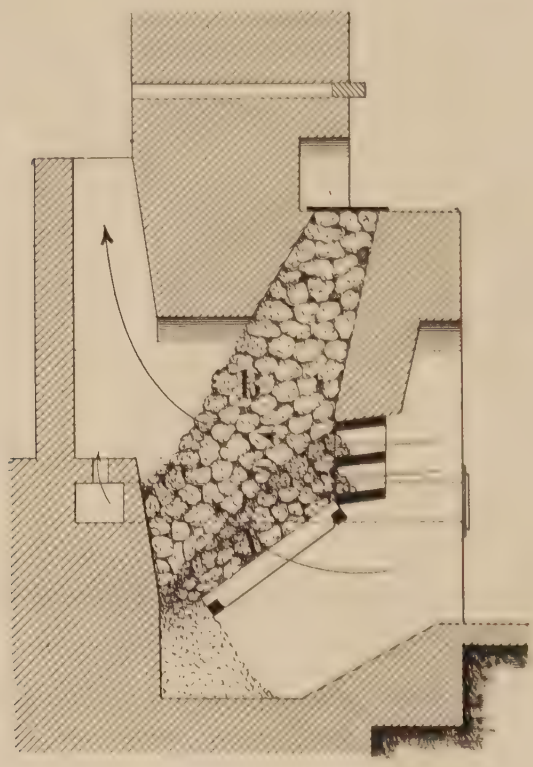



Fig. 150.—Kiln Fireplace.

there is a supplementary channel of warm air, but this gets in through a series of vertical openings placed in the hearth. The air is thus introduced parallel with the flames, and only causes their combustion in the interior of the kiln.

**159. Heating by Gas.**—Heating by gas necessitates the use of one or more gas generators with a system of channels connecting them with the kiln, and of burners placed in the kiln which consume the mixture of gas and air.

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The principal object of the *generators* is to change the carbon of the coal into a combustible gas. In fact, 2·2 lb. of carbon combines with 2·937 lb. of oxygen to make 5·142 lb. of carbonic oxide. This gas, in turn, burns by being changed into carbonic acid and producing, theoretically, 1,090 units of heat per lb., that is 5,600 units for the 5·142 lb. As, on the other hand, 2·2 lb. of pure carbon produces 8,080 units of heat, the loss due to being turned into gas would be 3,480 units, or 43 per cent.

This loss can, theoretically, be quite got rid of by using these 3,480 units of heat to decompose the water vapour, the oxygen of which would unite with the carbon to form carbonic oxide, and the hydrogen from the water would mix with the combustible gases to produce, by its final combustion, a quantity of heat exactly equal to that employed to decompose the water. These two methods of producing gas can be represented by the following equations :—

2·204 lb. carbon + 12·776 lb. air = 5·142 lb. carbonic oxide + 9·849 lb. nitrogen.
2·204 lb. carbon + 5·031 lb. air + 2·033 lb. water = 5·142 lb. carbonic oxide + 3·974 lb. nitrogen + 0·222 lb. hydrogen.

In this last case, the combustion of 5·142 lb. of carbonic oxide and of 0·222 lb. of hydrogen, of which the calorific power is 34,462 units, gives exactly the 8,080 units of the carbon; the loss then is *nil.* One sees also that in the first case the weight of the gas products is 14·980 lb., while it is only 9·239 lb. in the second.

These theoretical considerations are modified in practice; on the one hand, because of the hydrocarbons and the gases that all the fuels contain, and, on the other hand, because the water vapour is only decomposed at a high temperature that cannot be maintained in the gas generator, except at the cost of a considerable amount of fuel. The result is that, practically, the loss in the case of the use of air only is reduced to 30 or 35 per cent., and that it is lowered to scarcely above 15 per cent. by the use of air and water. It is unnecessary to add that, if the working of the gas generator is bad, if the combustion in it is too complete, it can no longer produce gas fuel, and the loss then is a total one.

This remark is sufficient to show that the value of heating by gas entirely depends on the working of the generator. If that is well constructed and well managed the inevitable loss in the gas production will scarcely exceed that which takes place in the fireplaces with grating or in furnaces. If the apparatus is bad and badly managed, then that system of heating is the most deplorable that can be imagined.

The great difficulty in gas production consists in the formation of clinker and rubbish. These are very troublesome to get away, and this operation often causes a considerable loss of fuel, and leads to grave disarrangements in the working. To this first inconvenience must be added another which is peculiar to fat coal, that is its tendency to cake and form a compact mass, which may completely stop the passage of the gas.

These inconveniences disappear very largely when one uses as fuel coke, anthracite or very sandy coal; but these fuels, which may be very good to use in other industries, usually in pottery give off gases which have too short a flame and often too little heat power. One is nearly always obliged to use open-burning coal in order to obtain good results.

At present gas generators are used with a natural draught, and generators with a blower. The exhaust generators which are obliged to cool and purify the gases before allowing them to pass into the exhaustion apparatus, are of no use in pottery.

In *generators with natural draught*, the drawing in of the air is made, on the one hand, by the draught of the chimney, and, on the other, by placing the generators sufficiently below the level of the burners to profit by the ascending force of the warm current of gas. The systems of generators of this kind are very numerous, but they have for the most part only restricted and ephemeral application. A study of their arrangements would only show a moderate practical interest, and would be out of the scope of this work. We will content ourselves then with mentioning two arrangements, applicable, one for coke, anthracite and very sandy coal, the other for open-burning coal which is recommended for its relative facility of working.

In the gas generator shown in Fig. 151 the fuel is put in by an upper opening, and fills a space of square or rectangular

section. It rests at the lower part on a grating in steps, and on an ordinary grate slightly inclined. A side opening allows of the escape of the gases, a pipe pierced with little holes takes in constantly some water which trickles into the ashpit. The latter is shut by a door which has an opening that can be regulated at will, allowing of the introduction of air. In order to manage the cleansing, a movable grate is put in with round and pointed bars, which takes the position shown by the dotted line, resting on the last step of the grating in stages, and on a projection in the masonry. This grate being put in posi-

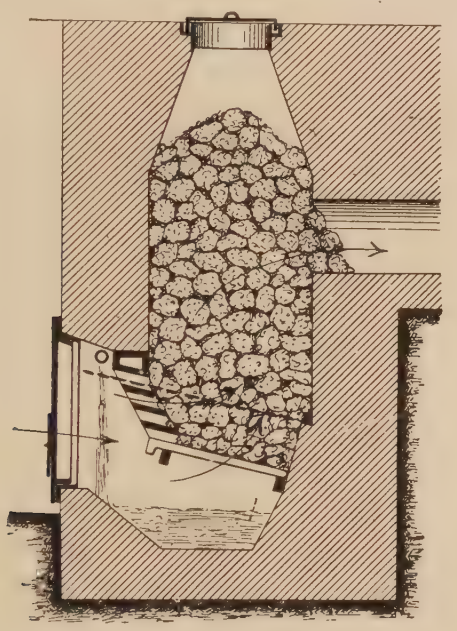

Fig. 151.—Gas Generator for Sandy Fuel.

tion, the fixed grate is raised, and the rubbish and clinker are drawn out, falling into the ashpit; then the fixed grating is replaced, and the movable grating taken out. This is done at regular intervals, every four to twelve hours. The fuel filling the upper pyramidal part serves to feed the generator during the interval between two charges.

For fat and caking fuels this arrangement would not be suitable; that shown in Fig. 152 must be used. A hopper with double closing, arranged to prevent the gas escaping, is used for charging. The fuel falls on an inclined plane, where it distils;

then passes on to a grating which is very sloping, where the carbon is changed into carbonic oxide. The ashes as well as the rubbish, which can be fairly easily got out by means of a fire-hook passed between the bars, descend into the ashpit by a space which is left between the lower end of the grate and the masonry. An upper opening, closed with a ball, allows of poking the fuel and of separating the pieces which have caked together. Lastly, an arrangement similar to that in the preceding figure serves for feeding with the water from the ashpit. Usually these gas generators are made without doors.

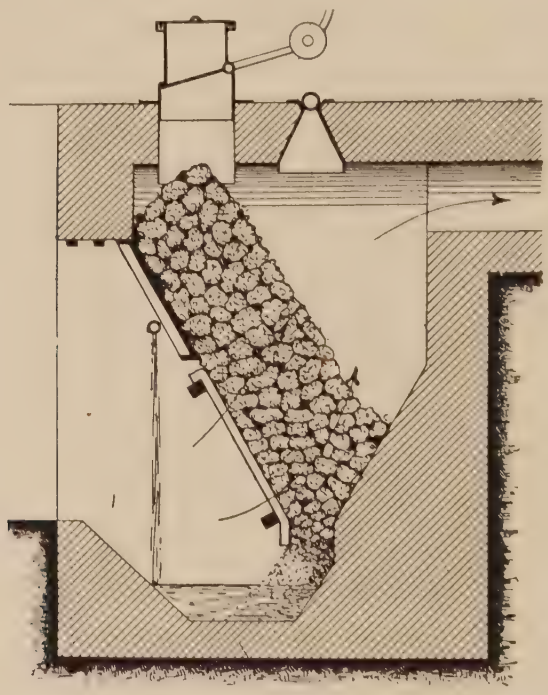

FIG. 152.—Gas Generator for Fat Fuel.

In the *blast gas generators* the air is introduced by pressure, either by means of a fan, or by an injector. They have the advantage over the preceding of allowing the pressure to be regulated at will, and also the production of gas, independently of the draught from the chimney, which is often of very great value for the good working of the kiln.

The blast, by means of a fan, exerts a certain moving power, which necessitates for nearly all ceramic purposes the employ-

ment of a special engine. On the contrary, the injector with a current of steam only needs a small auxiliary boiler, which is easily worked by the fireman of the generator. This latter solution then is simpler, less costly, and has besides the advantage of furnishing the gas generator with the steam, which, as we have seen before, is necessary for its economical working, the simple evaporation of the water from the ashpit being insufficient in all cases.

The blast can be adapted to the two types of generators already shown, provided that the door of the ashpit can be

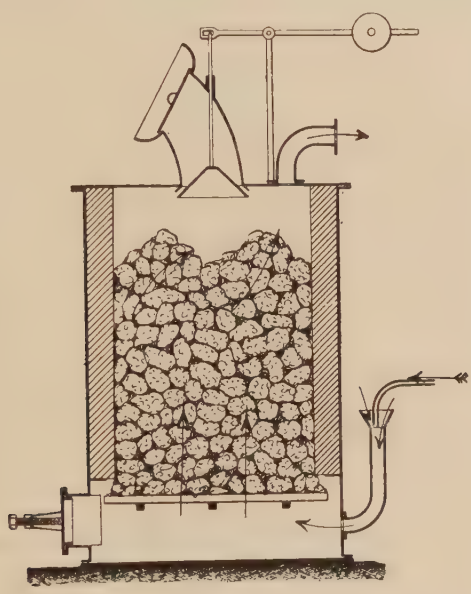

Fig. 153.—Blast Gas Generator.

hermetically closed. It is, however, preferable to make them of a cylindrical shape, and to place them on the level of the ground. For coke, anthracite, or pure sandy coal, the arrangement shown in Fig. 153 (Dowson) can be used. The fuel, which is introduced through an upper hopper with double doors, rests on an horizontal grate, under which is injected a current of air and steam. The gas produced passes out through a pipe placed at the upper end. The cleaning out takes place every twelve hours by one or two lower doors. This type of gas generator is particularly suitable to the production of poor gas, which, used for the production of motor-power, makes such a

noticeable competition with steam engines. It seems to have much less prospect in pottery, because of its exclusive use of sandy fuel.

The gas generator shown in Fig. 154 (Taylor) allows of the use of fatter fuel. With a working similar to the preceding, it differs from it by its automatic cleansing, which is done by making the lower cast-iron plate, on which the cinders and rubbish collect, turn over by means of a crank. The ashes, etc., are cooled and broken up by the current of air and steam which escapes from the central pipe. The rest of their breaking up is managed by means of the hooks that are pushed into the cone and their slipping at the moment when the plate turns

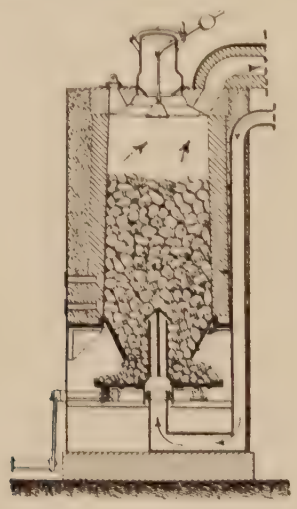

Fig. 154.—Blast Gas Generator.

over, thus effecting it without stopping the working of the apparatus.

The gas used in the pottery kilns does not need to be purified or stored in gasometers. The *system of channels* which joins the gas generators to the kilns is therefore very simple. Sometimes it is subterranean with brickwork conduits, sometimes in the open air with metallic pipes, which it is wise to line inside with fire-brick masonry. In all cases it ought to be air-tight and fairly non-conductive to prevent the cooling of the gas. When the gas generators are working slowly and use fat fuels, coal tar is deposited in them, which is got rid of from time to time by putting fire in them.

The firing of the gas in the kilns takes place at its exit from the *burners*, which are made of fire-brick, for the purpose of dividing the gas up so as to insure it mixing with the air. The more intimate this mixture is, the shorter are the flames, and the higher the local heat. If one wishes, therefore, to have very long flames, a very perfect mixture must be avoided, without, however, falling into the opposite extreme. The arrangements adopted for the burners depend upon the style of the kiln; further on we shall find some examples of them.

The air thus introduced into the kiln is called *secondary air*, in opposition to the name of *primary air* which is given to that which, in the gas generators, helps in producing the gas.

### (*b*) *The Draught.*

**160. Chimneys.**—The draught may be natural or forced. In the first case it is the result of the difference in weight between warm gases and cold gases. The weight of one cubic metre of gas at temperature $t$ is equal to its weight at 0° C. divided by $1 + at$, $a$ being the co-efficient of expansion of gases equal to 0·00366. There is no occasion in this connection to take account of the differences of pressure which are always negligeable in kilns, and one reckons a uniform pressure of 760 millimetres of mercury. If, then, we consider a chimney 10 metres high having a section of 1 metre square, and containing, for example, air at 200° C., we see that the weight of a cubic metre of air at 0° C. being 1·3 kilogramme, the weight of this column of air of 10 metres will be

$$\frac{1{\cdot}3}{1 + (0{\cdot}00366 \times 200)} \times 10 = 7{\cdot}5 \text{ kg.}$$

On the other hand, the weight of a similar column of air at 0° C. would be 13 kilogrammes. If we think of an opening 1 metre square at the base of the chimney, we shall see that the layer of air which is there supports on the outer side a weight equal to the pressure of the atmosphere, measured at the upper part of the chimney, plus 13 kilogrammes, while on the inner side it only supports a weight equal to the same pressure, plus 7·5 kilogrammes. There is then a difference in weight of 5·5 kilo-

grammes, or of 0·55 grammes per square centimetre, which obliges this layer of air to be displaced and to rise in the chimney.

Indicating in a general way by H the height of a chimney containing a gas at temperature $t$, of weight $d$ per cubic foot at 0° C., while the atmospheric air of a weight $\delta$ is at a temperature $\theta$, the difference in weight at the base of the chimney of section S will be given by the formula

$$\frac{HS\delta}{1 + a\theta} - \frac{HSd}{1 + at},$$

or

$$HS\left(\frac{\delta}{1 + a\theta} - \frac{d}{1 + at}\right).$$

If $e$ represents the height of a column of water having for its base the section of the chimney which balances this difference in weight, the depression caused by this chimney, measured in a column of water, is

$$e = H\left(\frac{\delta}{1 + a\theta} - \frac{d}{1 + at}\right),$$

$e$ being expressed in millimetres of water.

In the case with which we are now occupied, the weight $d$ of the gases passing out by the chimney is higher than that $\delta = 1·3$ kilogramme of the air, in consequence of the presence of a certain quantity of carbonic acid; from this fact it can at most amount to 1·41 kilogramme.

On the other hand, the steam has a tendency to diminish it, and the result is that one can on an average call $d = 1·35$.

The difference between $\delta$ and $d$ is so small that one can make $\delta = d$, and that, consequently, the depression caused by a chimney is equal to

$$e = Had\,\frac{1 - \theta}{(1 + a\theta)\,(1 + at)}.$$

One sees that it is proportional to the height H, but also to the difference of temperature $t - \theta$. If, in fact, one admits that $\theta = O$, the expression $\frac{t}{1 + at}$ gives for $t = 100$, 500 and 1000° C. the following values: 0·73 – 1·76 and 2·29, that is to say, proportional to 1 – 2·41 and 3·19, or approximately, to the square root of the temperature.

This draught ($e$) ought to be sufficient to overcome all

obstacles ($r$) which this gaseous current encounters in its passage across the kiln, and to give it, besides, a speed in the chimney great enough not to be too much affected at its exit by the wind. The ascending motion then is produced in ratio to the depression $e - r$. The corresponding speed is given by the formula

$$v = \sqrt{\frac{(e - r)\,(1 + \alpha t).\,2g}{d}}.$$

It must not be below 1·5 or 2 metres. Knowing $t$ and $r$, one can deduce from them the height H of the chimney.

The resistance ($r$) made by the furnace to the gaseous current, measured in *millimetres* of water, can only be valued by experience in existing kilns, so that generally in practice the determining the height of the chimneys is settled by comparison with other installations. As to the section S of the chimney, one can easily find it by determining the volume V of gas necessary for combustion and dividing it by the speed $v$.

If one admits that $r = ae$, that is to say that the loss in the charge which is due to the resistance of the kiln is a simple action from the draught of the chimney, the value of the speed $v$ becomes

$$v = \sqrt{\frac{2ge\,(1 - a)\,(1 + \alpha t)}{d}},$$

or, replacing $e$ by its value,

$$v = \sqrt{\frac{2g\mathrm{H}\alpha\,(1 - a)\,(t - \theta)}{1 + \alpha\theta}},$$

from which one deduces for the volume of gas delivered by the chimney

$$\mathrm{V} = \mathrm{S}\sqrt{\frac{2g\mathrm{H}\alpha\,(1 - a)\,(t - \theta)}{1 + \alpha\theta}}.$$

From the preceding formulæ one can deduce:—

1. That the draught produced by a chimney is proportionate to its height and about to the square root of the difference between the interior and exterior temperature.

2. That the volume of gas delivered by a chimney is proportionate to the section and to the square root of its height and of the difference in the temperatures.

3. That if, in the preceding formulæ, one admits H = 1 metre,

$\theta = O$, $S = 1$ square metre, one finds the following quantities represent the depression, the volume, and the weight of air delivered in a second, by a chimney 1 metre high and 1 square metre in section for the increasing temperature $t$:—

| Temperature. | Depression. | Volume. | Weight. |
|---|---|---|---|
| ($t$) | ($e$) | (V) | (P) |
| 10 | 0·046 | 0·848 | 1·071 |
| 50 | 0·201 | 1·897 | 2·073 |
| 100 | 0·347 | 2·683 | 2·538 |
| 150 | 0·459 | 3·286 | 2·741 |
| 200 | 0·547 | 3·795 | 2·829 |
| 250 | 0·619 | 4·242 | 2·861 |
| 300 | 0·678 | 4·648 | 2·860 |
| 350 | 0·727 | 5·020 | 2·841 |
| 400 | 0·769 | 5·366 | 2·811 |
| 500 | 0·837 | 6·000 | 2·736 |
| 700 | 0·931 | 7·098 | 2·572 |
| 1,000 | 1·016 | 8·485 | 2·349 |

We see that the weight $P = \frac{1 + at}{Vd}$ of the air delivered from a chimney, increases when the temperature of the chimney passes from 0 to 300° C., till it attains a maximum, and afterwards decreases again.

Practically, we also see that after $t = 150°$ C. it scarcely varies any more, and that there is no need, in order to increase the weight of air delivered, to pass that temperature. On the other hand, it also must not fall below 50° C., which would need large chimneys, working badly, because they would be too dependent on the atmospheric variations, and the cooling of the gases being too great might lead to the condensation of the steam which they contain. A temperature slightly above 100° C. is that which, from all points, is the one to be preferred.

Instead of chimneys, mechanical engines can be used, and thus a *forced draught* be obtained. Fans have been used for this purpose and injectors of steam. These apparatus are not to be recommended except when great draughts are necessary, which is never the case in the ceramic industries. Besides, the presence of sulphurous gas and water vapour causes the formation of sulphuric acid, which at a sufficiently high temperature rapidly spoils the draught fans. As to fan blowers, their use is generally difficult, if not quite impossible.

**161. The Draught in the Kilns.**—What has just been said on the subject of chimneys is equally applicable to kilns, which, by their vertical position, are themselves chimneys. The height H is the difference in level that there is between the openings for the entrance of the air and the escape of the gases. Often certain parts of the kilns have a tendency to increase or diminish the draught. If, for example, one considers a kiln

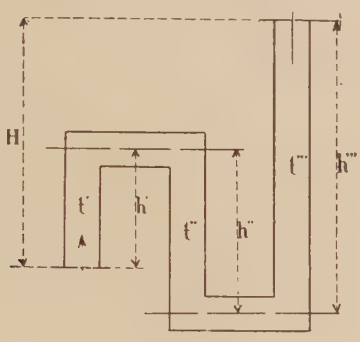


Fig. 155.

the circulation in which is represented by the scheme in Fig. 155, the depression will be shown by the difference

$$\frac{H.\delta}{1+\alpha\theta}-\left(\frac{h'd}{1+\alpha t'}-\frac{h''d}{1+\alpha t''}+\frac{h'''d}{1+\alpha t'''}\right),$$

the ascending parts increasing the *depression* and the descending ones diminishing it.

In particular, if the arrangement of Fig. 156 is examined,

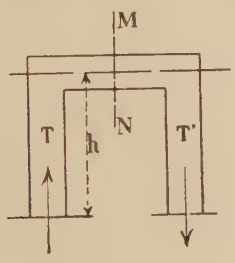


Fig. 156.

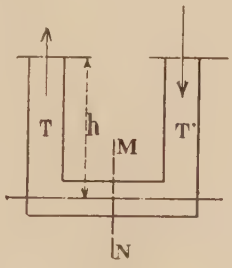


Fig. 157.

in which the circulation is formed by an ascending current of temperature T and by a descending of temperature T′, we see that in a section MN the difference of pressure is

$$\frac{hd}{1+\alpha T}-\frac{hd}{1+\alpha T'}.$$

If T is greater than T′, the motion of the gases is produced

in the direction indicated by the arrows going from the current T to the current T'.

In the contrary arrangement (Fig. 157) the same reasoning shows that the circulation is produced in the reverse manner, going from T' to T.

This double observation can be shown in another way by saying that the draught is increased when one raises the temperature of the ascending gases and that of the descending gases is lowered, and that it is diminished, on the contrary, when the case is reversed. We see also that it is not necessary that there should be a difference in the level between the entrance for the air and the escape for the gases in order to set up a gaseous circulation in a kiln.

In the burning space the movement of the flames and the gases may be ascending, descending or horizontal. When this circulation is *ascending*, it is necessary, in order that it may be regular, that the temperature should be absolutely uniform on each horizontal plane. If in any one place the temperature is raised, it has a tendency there to make a quicker circulation, and in consequence to attract the flames there, so that the defect is more and more aggravated. There are then formed, in the middle of the ware in the kiln, vertical currents that are very great and very hot, called in practice by the name of chimneys, which afterwards it is often very difficult to stop, and which may endanger the success of a firing.

It is not the same when the circulation is *descending*. If then at one point there is a rise in temperature, the draught becomes less; the flames are carried there less, until the evenness of the temperature, which was interrupted for a moment, is re-established. Thus the descending circulation has a tendency to make the temperature uniform, which may have been rendered unequal by a fault in working, while, on the contrary, an ascending circulation has a tendency to aggravate this initial fault.

When the burning space is crossed by an *horizontal* current, if this is hotter than the ware which is firing, it has a tendency to rise and follow the dome; if, on the contrary, it is colder, it descends and circulates along the lower part. The errors in

temperature then are likely to be aggravated. This tendency can be met by increasing the obstacles to the current in the upper part and diminishing them in the bottom. A judicious charging usually attains this end.

**162. Regulation of the Draught.** — The regulation of the draught in the kilns is for the purpose of varying, on one hand, the speed of the current, and, on the other, the weight of the circulating gases.

The regulation of the *speed* is necessary: (1) so as to have a good combustion in the furnace, because it ought to be between certain limits, which vary with the dimensions of the fuel and the thickness of the layer; (2) so as to make good use of it, as the gaseous current ought to circulate slowly enough among the ware to give it time to transmit its heat to them.

For regulating the *weight* of the gases, on the contrary, it depends on the quantity of fuel consumed, and consequently on the intensity of the fire.

This double regulation is caused by giving, while constructing the kilns, special narrow sections to certain parts of them, and by putting in others openings of various sizes. At certain places also air can be made to enter. The openings of a certain size are usually placed between the fireplace and the burning space, and between the latter and the chimney. The regulating openings are at the entrances for air and at the exits for the gas. For this purpose clack-valves with hinges, dampers and valves are used.

The clack-valves are only placed at the top of the chimneys; they are worked from below by a chain and a balance weight. They have scarcely any other use than to completely close the opening when the working of the kiln is needed to be stopped, because they are not suitable for an exact regulation of the draught.

When the dampers are vertical, they are hung by a chain which passes over a roller and balanced by a balance weight. The working of them is very easy; on the other hand, they do not close hermetically. In order to obtain the latter, horizontal or sloping dampers must be used, which slip on their seat, and are kept in place by their weight. The dampers

may be either cast-iron or fire-brick, according to the heat to which they are to be subjected, whether it is higher or lower.

Valves are usually round covers that are raised more or less. Very often, so as to get a more exact regulation, they are given a conical form. In order to allow of their closing hermetically, they can be ground on the surface which comes in contact with the seat, or even their edges can be dipped into a sand bath that is deep enough. The working of them is done by a screw or by a differential tackle. The valves are scarcely ever made except of cast iron; although they form very good regulators for moderate temperatures, they cannot be used when exposed to a great heat.

It is easy to understand that all these apparatus, by varying the opening for the passage of the air, increase or diminish to about the same proportion the volume of gas which circulates in the kiln, but they do not act in the same way on the depression. If, in fact, the working of a periodical kiln, the temperature of which rises evenly, is studied, we have seen that after the time when the gases that pass into the chimney have reached a temperature of 150° C. the volume that is given out becomes almost constant, but that the depression keeps on increasing. If one wants to reduce it so as to keep a regular working of the fire, one is often obliged to lessen the aperture of the apparatus for regulating it, in such a proportion that the weight of gas given off becomes insufficient. Then a special opening by the side of the damper must be opened, to allow a certain quantity of air to come in from outside, which, it is true, diminishes to a certain proportion the weight of the gases given out, but which acts in a much more efficient way on the depression. This inrush of cold air has besides the advantage of cooling the damper as well as the chimney, and consequently of preserving them from the action of too great a heat.

These general observations on the draught will be found completed by a description of the construction and working of the different systems of kilns.

### (c) *Kilns.*

**163. Classification of Kilns.**—The heat is made use of in one or more baking spaces (chambers), which constitute the kiln properly so called, in a more restricted acceptation of the word. The arrangement of these spaces is a characteristic of the kiln and acts as a basis for classifying them.

In most pottery kilns the heat is used *direct*, that is to say that the ware or the receptacles which contain it are directly exposed to the action of the flames and of the hot gases. In other kilns, called muffle kilns, the action is *indirect*, the flames heating the outside walls of the baking chambers without going inside them. The kilns of the first class are used for the burning of goods which are spoiled by contact with the flames, and for those which, although needing to be protected by special receptacles, called by the name of saggers, yet require to be burnt at a high temperature. The kilns of the second class are only used for delicate ware, which only requires a moderate temperature for burning.

For these two classes of kilns the burning may be intermittent or continuous. In the first case there is usually only one single burning chamber, while, in the second case, either the single chamber forms a continuous current, or a series of chambers, also forming a circuit, are joined to one another.

The classification then includes four sub-classes that can be re-divided at pleasure into several kinds, according to the direction of the flames and gases in the burning spaces. Thus a very methodical and fairly rational classification would be obtained. Yet for industrial purposes, which are the object of this work, it seems to us to be preferable to content ourselves with classifying them in seven divisions:—

1. Intermittent kilns with up draught.
2. Intermittent kilns with down draught.
3. Horizontal intermittent kilns with one firehole.
4. Continuous kilns with one burning space.
5. Continuous kilns with several burning spaces.
6. Horizontal intermittent kilns with several fireholes.
7. Muffle kilns.

**164. Intermittent Kilns with Up Draught.**—At the commencement of potting, the goods were simply placed to be burnt in the middle of a brazier of wood, which method has made it possible to manufacture those large jars that were mentioned in Art. 10, which it was impossible to move in an unburnt state, and which it was necessary to bake at the place where they were moulded. Even now a similar method is still employed in burning ordinary bricks in clamps, which consists of piling up the goods, putting alternately a layer of bricks and a layer of sandy coal. This particular method of burning will be described in the chapter devoted to the manufacture of bricks.

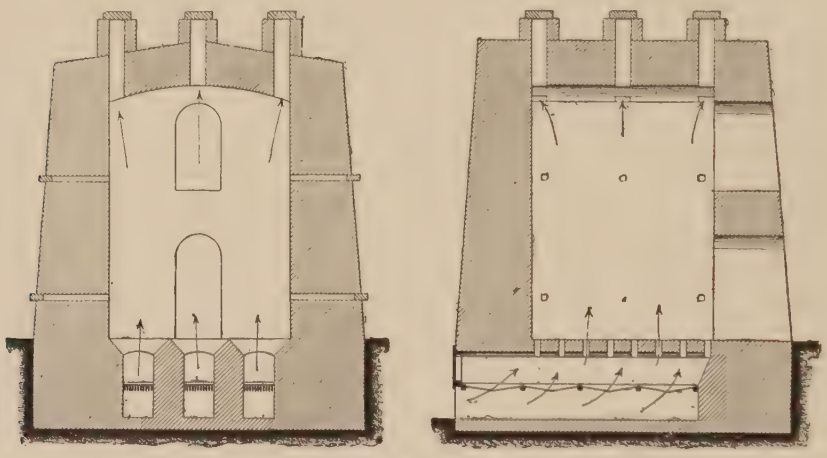

Fig. 158.—Square Kiln with Up Draught.

The first improvement in the kiln consisted in surrounding it with brickwork, the hollow interior of which formed the burning space; next, the fireplace was isolated, being placed under the chamber; and, lastly, the latter has been vaulted, and in this vault have been arranged several openings forming chimneys. Thus the kiln shown in Fig. 158 was obtained; for a long time this was the type of pottery kilns. Its use can still be of service in new countries, where intelligent workmen cannot be obtained, where fuel is cheap and the manufacture limited. In the drawing, fireplaces suitable for heating with coal have been put, but just as easily fireplaces for heating with wood could be adapted to it (Figs. 140 and 141).

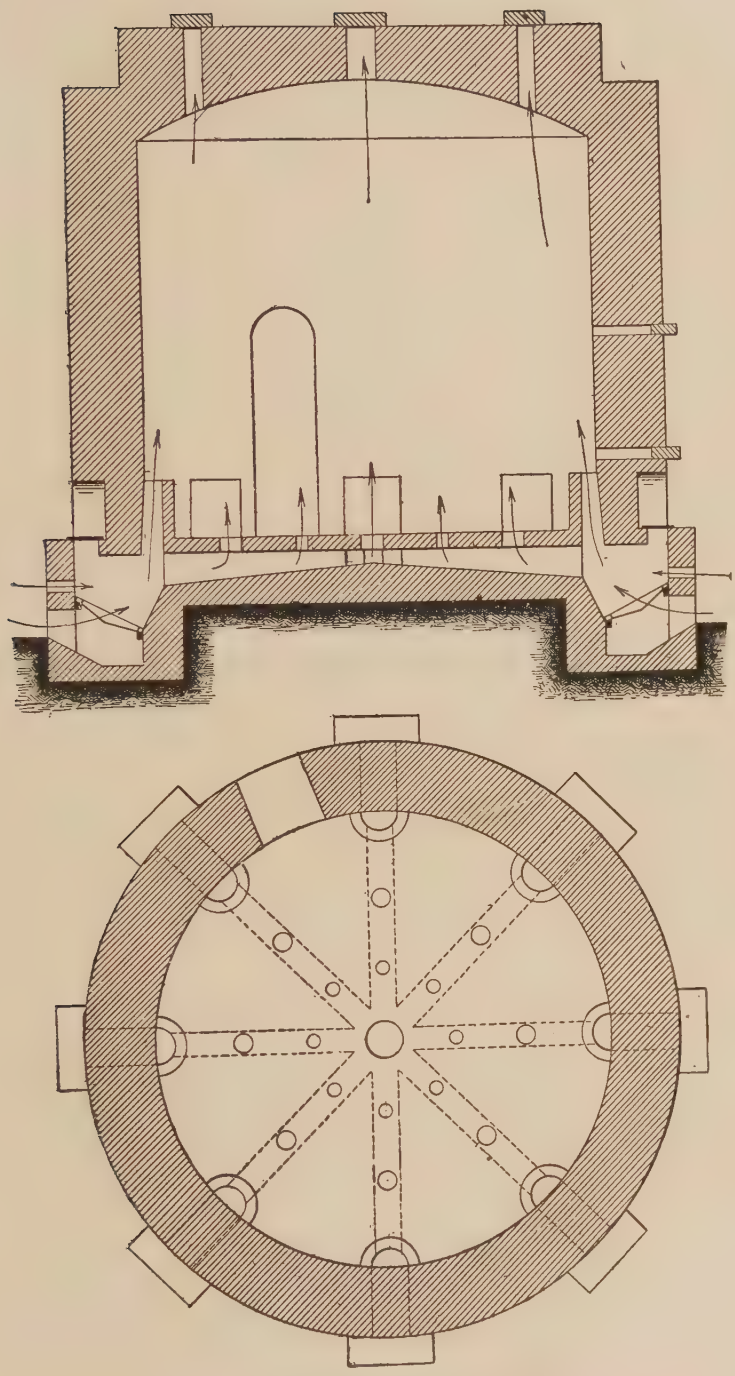

Fig. 159.—Round Kiln with Up Draught.

Two side doors, placed over one another, which are walled up during the burning, are used for charging and emptying. The openings for exit of smoke, made in the dome, are covered over with terra cotta slabs, which help to regulate the draught. Lastly, it is wise to strengthen the kiln by means of vertical supports of wood or iron, fixed at their base in the ground, and joined in the upper part by iron bands passing over the dome. As to the shape of the burning chamber, it may be, according to circumstances, square or rectangular.

The second type of intermittent kiln with ascending flames, shown in Fig. 159, was invented by Parent in 1769.

The burning chamber is of a round shape, which lends itself better to the equal distribution of the heat. The heating is done by several lateral fireplaces, spaced regularly on the perimeter of the kiln, the flames penetrating to the burning chamber through lateral openings and through the openings in the lower hearth. The draught is caused by openings arranged in the dome, and the feeding is done by one or two doors, the thresholds of which are on a level with the hearth. Lastly, circular iron bands help to strengthen the kiln, principally put above the fireholes, and on a level with the springing of the dome.

This type of kiln is mentioned because it is still frequently used, and because the invention of it was at the time a very great improvement, marking one of the principal stages in the history of pottery burning.

Setting aside the clamp kiln, which is quite a special kind, and apart from the cases mentioned for square and rectangular kilns, intermittent kilns with up draught ought to be in a general way absolutely condemned. They have the double defect of giving a wasteful use and an unequal distribution of heat. In this same class ought to be put square open kilns, round kilns with an upper storey and up draught, as well as other different arrangements which only deserve to be forgotten.

**165. Intermittent Kilns with Down Draught.**—The list of intermittent kilns with down draught is represented by four types :—

The rectangular kiln.
The round kiln.
The round kiln with an upper dome.
The round kiln with a lower dome.

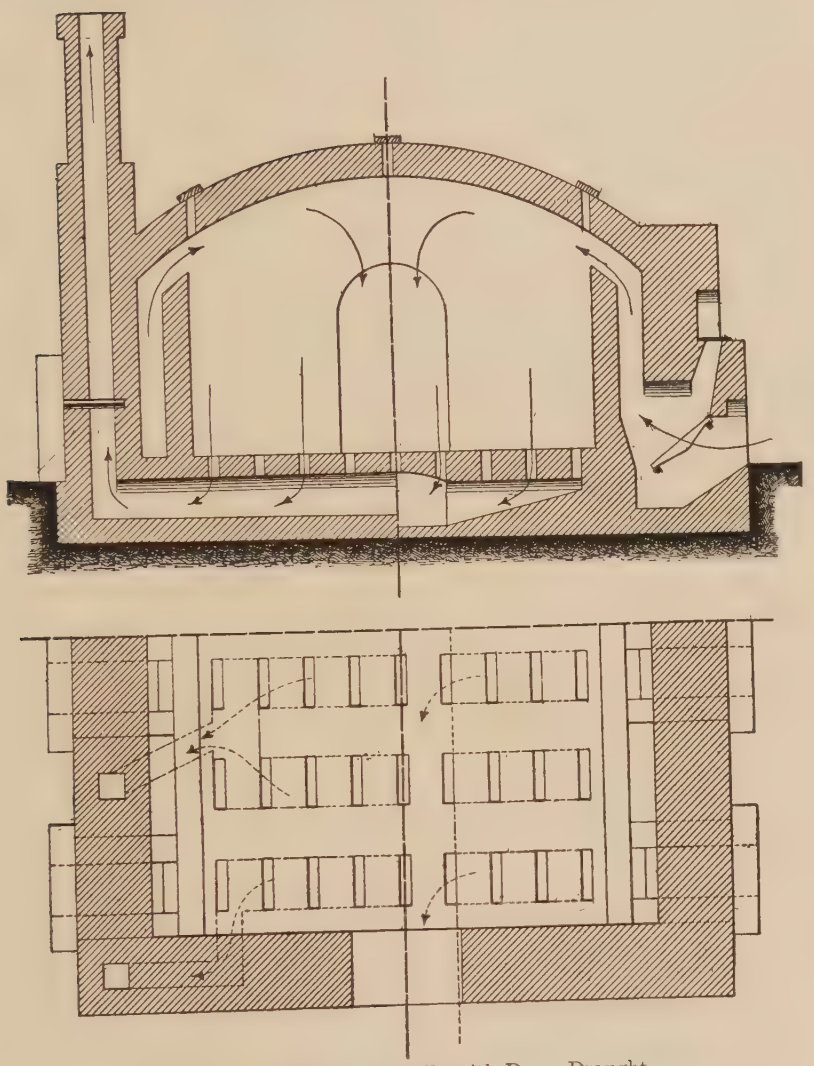

Fig. 160.—Rectangular Kiln with Down Draught.

In all these kilns the heating is done by side fireholes, for which, in certain cases, gas burners can be substituted.

The *rectangular kiln*, shown in Fig. 160, can be built with a single independent chimney, or with a series of chimneys in the thickness of the side walls. The right part of the figure

shows the first arrangement, and the left part the second one. The burning chamber, of rectangular form, surmounted by a dome, can be extended in length, so as to get the size wished for. But for a great length the arrangement of separate chimneys is preferable, the draught not being so easy to regulate uniformly with a single chimney. A door at each end is used for charging. The kiln ought to be strengthened solidly by girders put on each side of the fireholes, and joined together by tie-rods above.

This kiln is used for the burning of bricks and of terra cotta for buildings, the charging of which is difficult to do in round burning chambers. Yet the employment of it ought to be strictly limited to goods which, for reasons that will be explained in Chapter IX., cannot be burnt in kilns with continuous firing.

The *round kiln* (Fig. 161) is built of very different dimensions, according to the kind of objects to be burnt and to the temperature to be obtained. The fireplaces, which number two to twelve, are spaced regularly on the circumference. When the diameter of the kiln is large enough, they are united together by conduits placed underneath the floor, which join in one central entrance for the flames, as is shown in the figure. When, on the contrary, the diameter is small, the peripheric entrances for the flames have to suffice. In any case, the exit for the gases is made in the floor, by orifices, the arrangement, number, and dimensions of which depend on the kind of goods to be burnt and the method of charging them. All the openings lead into a central space, which, by an underground passage, communicates with an outside chimney that usually is one in common for several kilns. An upper opening is used for hastening the cooling when the burning is finished; one or more doors, on the level of the ground, allow it to be looked after.

This kiln is specially used for burning faience and stoneware; the working of it, although slightly better than that of round kilns with up draught, is, however, only medium, but with a suitable manner of charging the distribution of the heat is satisfactory.

The *round kiln with an upper dome* (Fig. 162) is used for

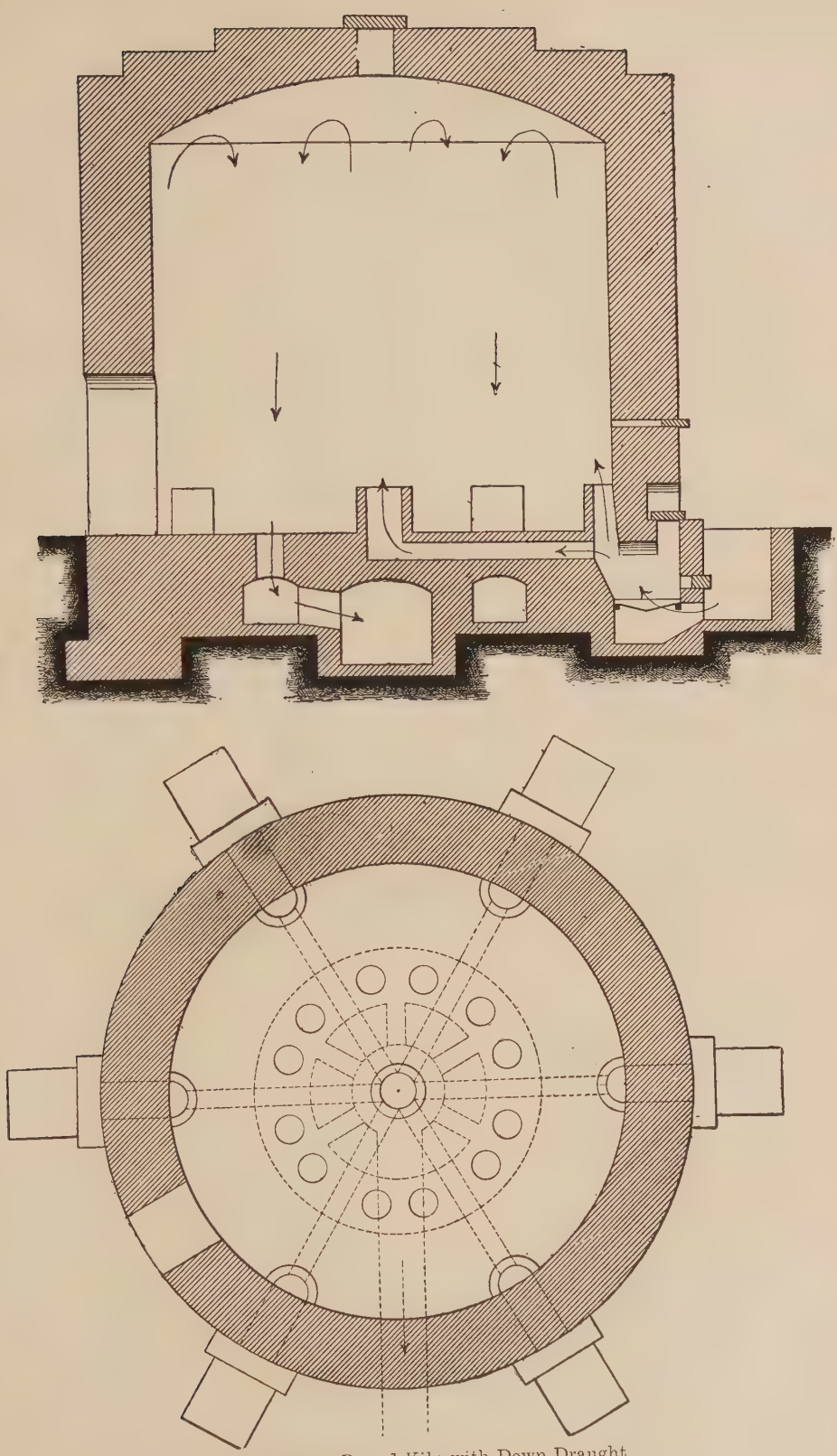

Fig. 161.—Round Kiln with Down Draught.

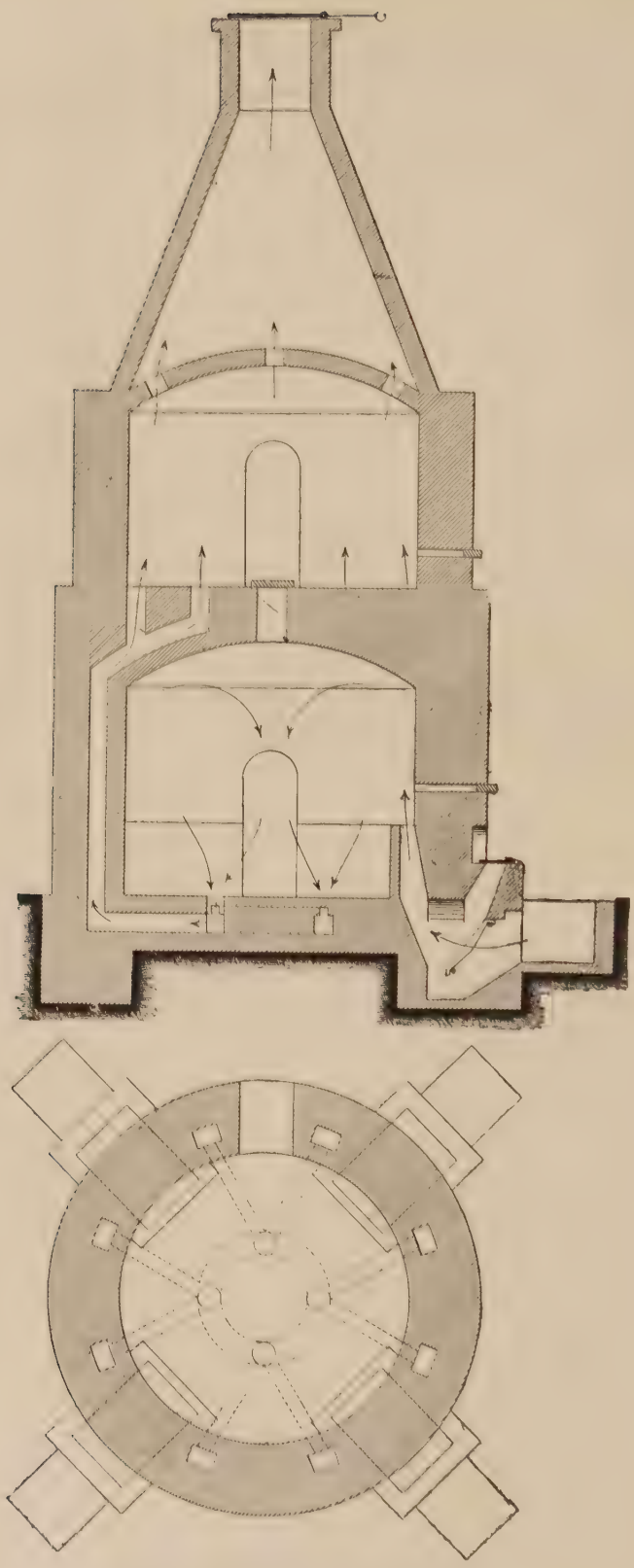

Fig. 162.—Round Kiln with an Upper Dome.

burning pottery, which has to be burnt or heated first before receiving the glaze (Minton), this heating being done in a second burning chamber, called by the name of a dome, by means of the flames rising out of the first. The working of the latter is the same as that of the former round kiln, but the flames, instead of being united in a collector, to pass thence into the chimney, rise through a series of vertical flues arranged in the walls, to come out through several openings in the bottom of the dome. There they continue their upward motion, crossing the crown of the dome, to go back into the chimney which is over the kiln.

Fig. 163 shows a similar arrangement, but *with a lower dome,* the heating of this being very simply done through openings arranged in the roof which separates the two chambers. This method is applicable when the heat for burning in the dome need not be noticeably below that of the upper chamber. If, on the contrary, there is required a warming through at a rather low temperature, as is the case for porcelain, it is better to make use of the arrangement shown in Fig. 163, in which the flames, coming out of the bottom of the upper chamber, descend by flues arranged in the walls to emerge at the level of the bottom of the dome. There they rise towards the crown, then descend in the middle of the goods, and pass out by lower openings, collecting again in a receiver, to go afterwards to an outside chimney.

In these two types of kilns with domes the utilisation of the heat is fairly good, slightly better in the second than in the first, in which sometimes it is necessary to finish heating the dome with supplementary furnaces placed at the upper floor. If heating by gas is adopted, it must be fitted to the kiln with a lower dome, which lends itself much better than the other to heating, by the gathering together of the secondary air.

The continuous kilns with descending flames divide the heat much better than those with ascending flames, but the utilisation in them of the heat, although generally a little better, is still very medium. It is increased by using globes and by heating with gas, which makes the kilns as economical as is possible

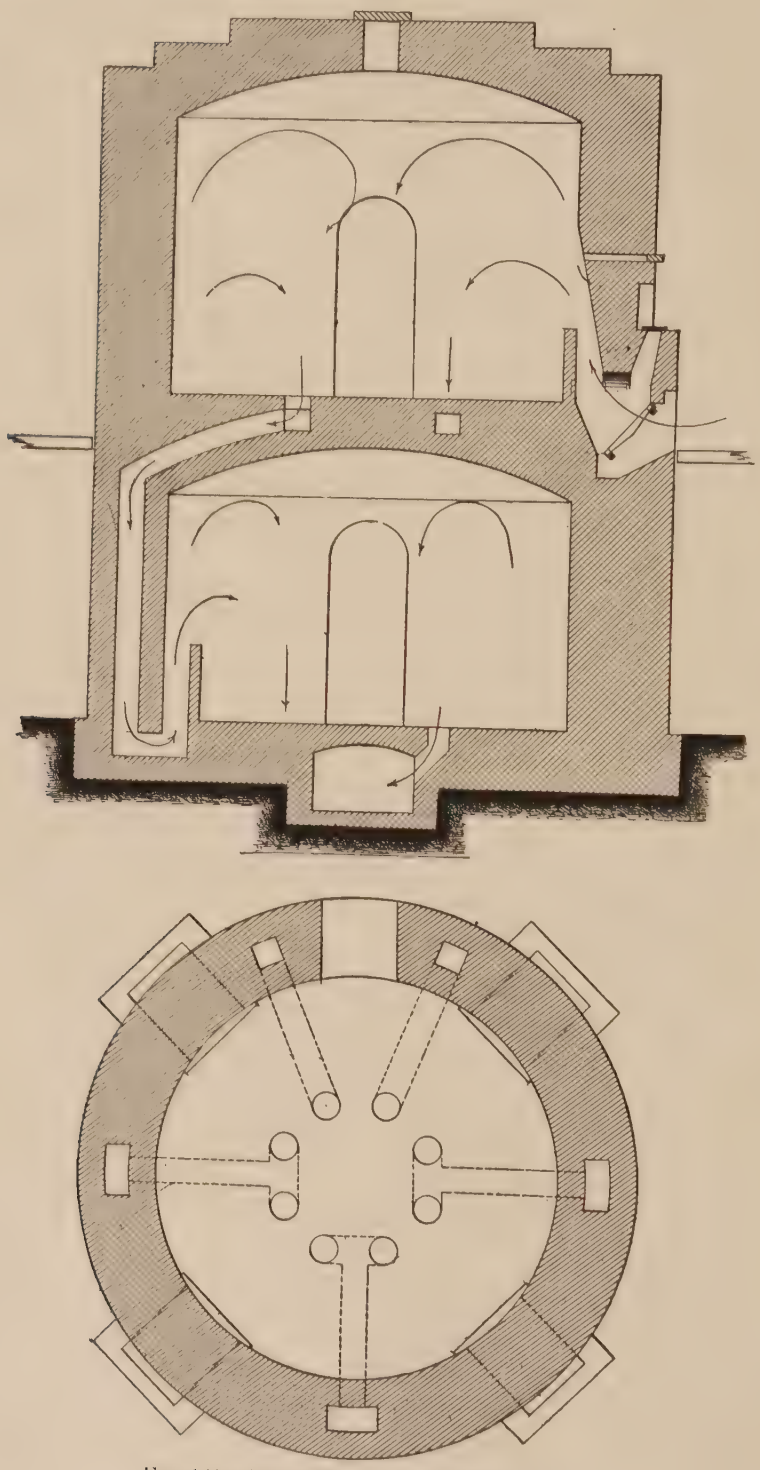

Fig. 163.—Round Kiln with a Lower Dome.

with intermittent burning. It is convenient to use these kilns for burning all pottery that needs a careful firing, and which it has not yet been possible to fire suitably in kilns with continuous firing.

**166. Horizontal Intermittent Kilns with Single Furnace.** — These kilns are characterised by their horizontal shape, and by a single fireplace put at one end, while the chimney or draught channel is at the other. The types that come under this section are fairly numerous, but it will be sufficient to mention shortly the three following ones :—

Fig. 164, a kiln with flames that are exclusively horizontal; when several of them are placed side by side, the draught is formed by a single chimney which communicates with a smoke

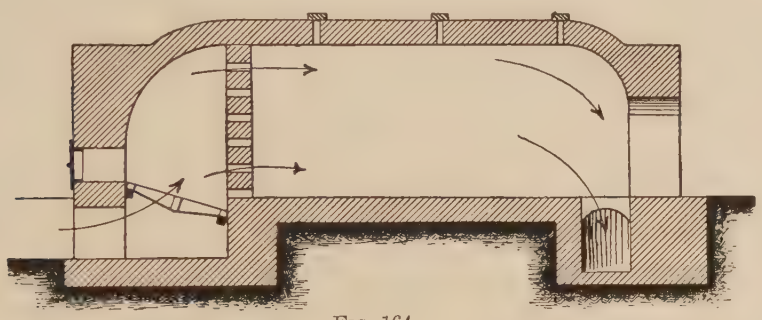

Fig. 164.

receiver; in the opposite case, the kiln is finished by a chimney as in the following examples.

Fig. 165, a kiln with flames that ascend first and then are horizontal.

Fig. 166, a kiln with descending flames that are more or less oblique.

All the kilns of this class have the inconvenience of this difficulty: either the kiln is short, the distribution of the heat is fairly good, but the utilisation of it is very bad; or else the kiln is long, the utilisation of the heat better, although still very moderate, but the distribution is shockingly bad. Before the invention of round kilns, they were frequently used for getting high temperatures, but they ought now to be absolutely condemned.

**167. Continuous Kilns with Single Firing Chamber.** — Con-

tinuous firing can be obtained by two very different methods. Goods piled on carriers can be made to circulate in a continuous or intermittent way across the fixed fireplaces, or else these fireplaces can be put in the middle of immovable goods.

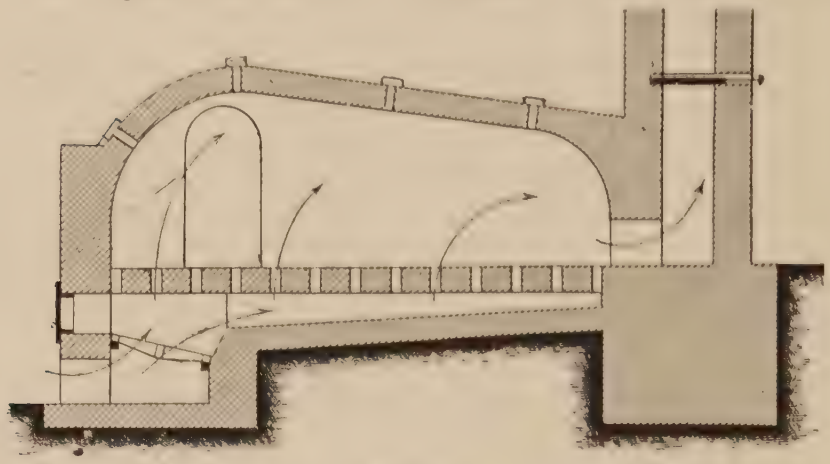

Fig. 165.

The first method, in spite of numberless attempts (by Demimuid (1854), Péchinet, Borrie, Colas, Dueberg, Curot, Bock, Maillet and Ramez, etc.), has now been entirely abandoned. Besides, it is easy to see that it is much simpler to move the currents

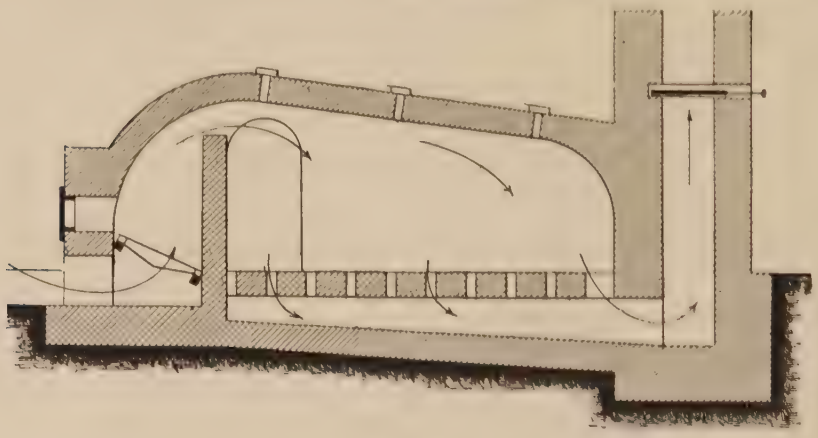

Fig. 166.

of gas than the very heavy goods, which are given a very high temperature. A description of the very ingenious arrangements which have been tried would only be of historic interest.

In the second method, the fireplaces, even while in action, can either be moved about, over the fixed goods, or else the fires can be spread about in the burning chamber, where they are lighted and then put out afterwards. The first arrangement (Barbier, 1855) has also been given up; there is, therefore, no need here to concern ourselves except with the second one.

Before beginning the description of the different types of kilns with continuous firing and a single chamber, we will first mention the principle of burning with a continuous fire, in the simplest case (Hoffmann & Licht, 1858), shown in elevation and plan on Fig. 167. A circular burning chamber, A, having twelve doors for charging, B, communicates, by means of twelve passages for the smoke, C, which can be shut by valves, F, with a receiver which itself is united by opening with the central chimney, D. A movable damper, which completely shuts off the burning chamber, can be placed near each door; on the drawing it is shown by the side of door No. 1. The space enclosed between two consecutive registers is called a chamber. The kiln then has twelve chambers, each of them having a door for charging at one end, and a draught passage at the other.

Thus placed, supposing that the kiln is working normally, the chambers 1 and 2 are being charged and emptied; the feeding is done by door No. 2. The chambers 3, 4, 5 and 6 contain goods which are burnt and cooling. The chambers 7 and 8 are being heated by the great fire. Chambers 9, 10, 11 and 12 contain baked goods which are being gradually heated. The air that is necessary for combustion, brought by the draught of the chimney, enters through door 2, which alone is open, all the others being built up, and passes through the whole length of the burning chamber. It cools the burnt goods in its progress, and arrives in the chambers that are being fired, having a temperature equal to that of the burning. After having been used in combustion, it continues its progress, crossing the ware to be burnt; this it heats in its progress, and finally arrives at the last compartment, of which the draught valve, F, is open, all the others being closed, and goes thence into the chimney.

When the burning of the seventh chamber is finished, the damper placed between the 12th and 1st is taken away, and put

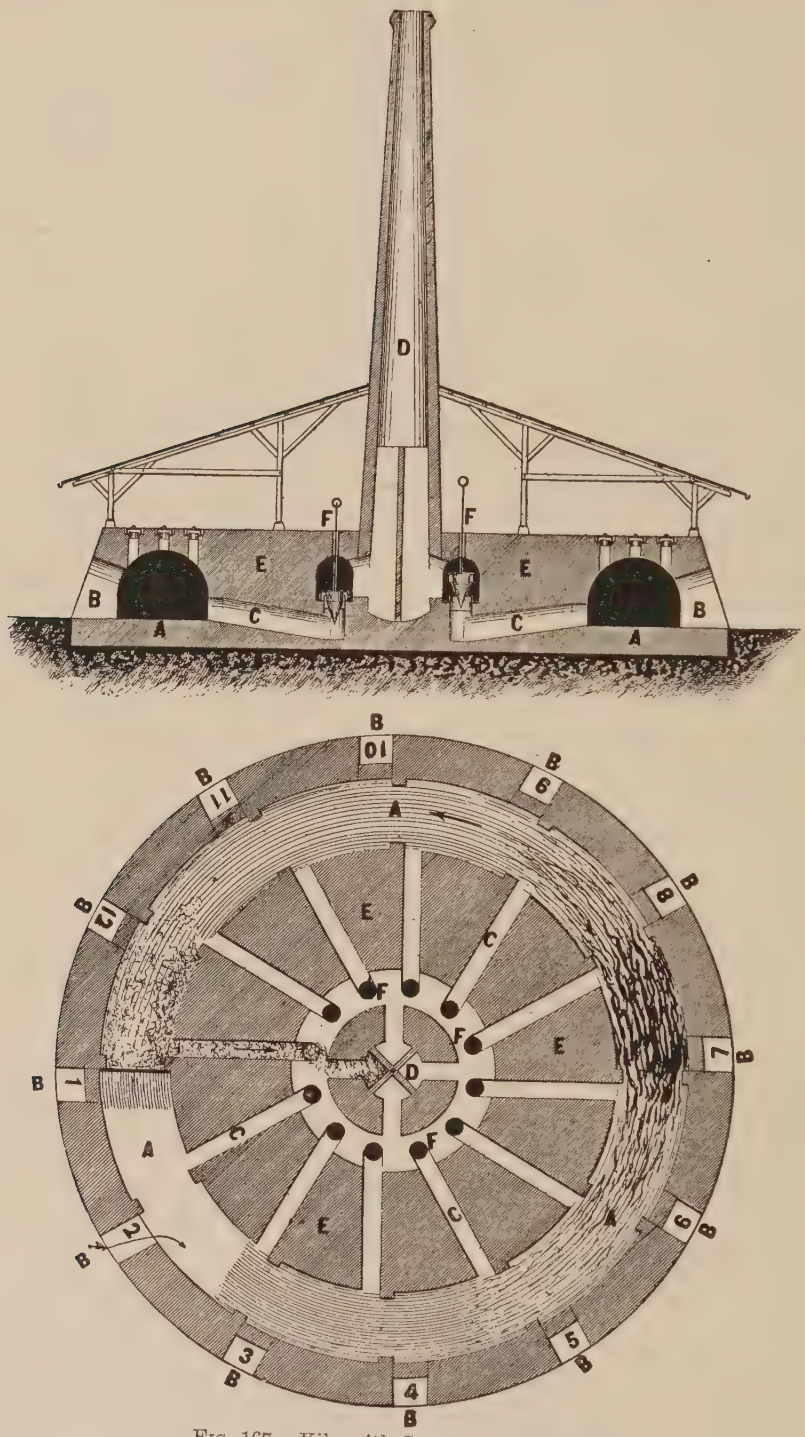


Fig. 167.—Kiln with Continuous Firing.

between the first, which has just been charged, and the second, that is finished emptying. The draught valve of the first compartment is opened, while that of the second is shut, the door 3 is undone, and door 2 is built up; the different phases of the burning go on in the same order, but have advanced one chamber. This is continued indefinitely, progressing at the rate of 1 or 2 chambers every twenty-four hours, the charging, emptying and burning being done in a continuous way. The starting is accomplished by building in some part of the burning gallery temporary fireplaces, by means of which the ware is sufficiently heated to ensure the catching fire of the fuel thrown in through the nearest heating shafts. These

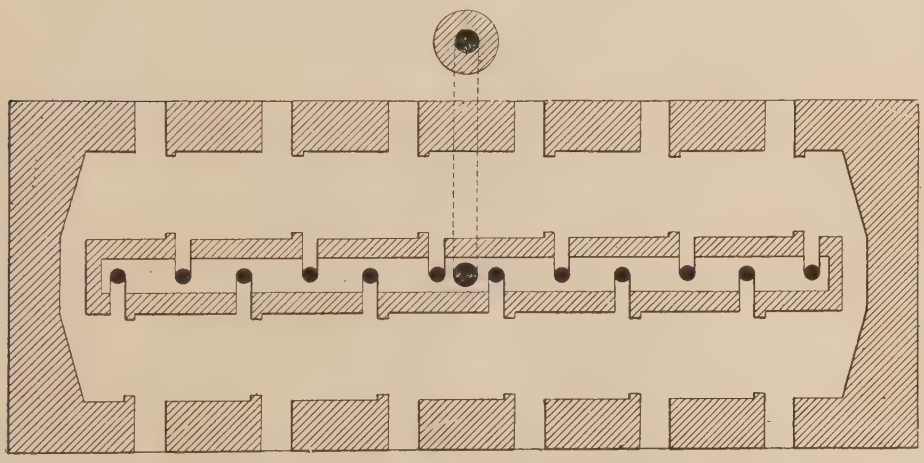

Fig. 168.—Kiln with Continuous Firing.

furnaces are kept going until the kiln has begun its normal working, then they are broken down.

In kilns of this type the burning chamber was at first circular as shown in Fig. 167; later, on account of economy of construction, they were given an oblong form (Hoffmann, 1870), then a rectangular form, composed of two parallel galleries united by two flues of communication at the two ends (Buhrer, Hamel, Simon). This shape, now almost the only one used, is shown in Fig. 168. The chimney is generally outside, as the illustration shows. For very small things sometimes different forms have been adopted, such as zigzag; one of these is shown in Fig. 169, but these, except in some very special cases, are not to be recommended.

The heating is done as has been described in Art. 156, and by placing the ware as is shown in Fig. 143. Wood can be

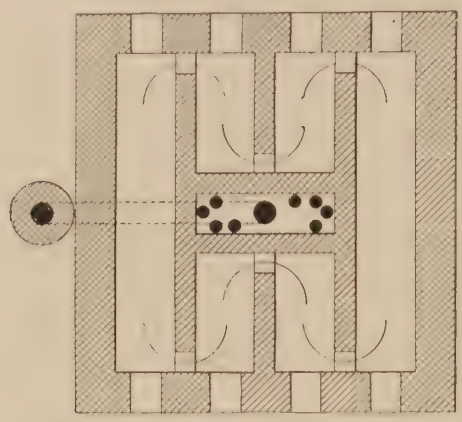

FIG. 169.—Kiln with Continuous Firing.

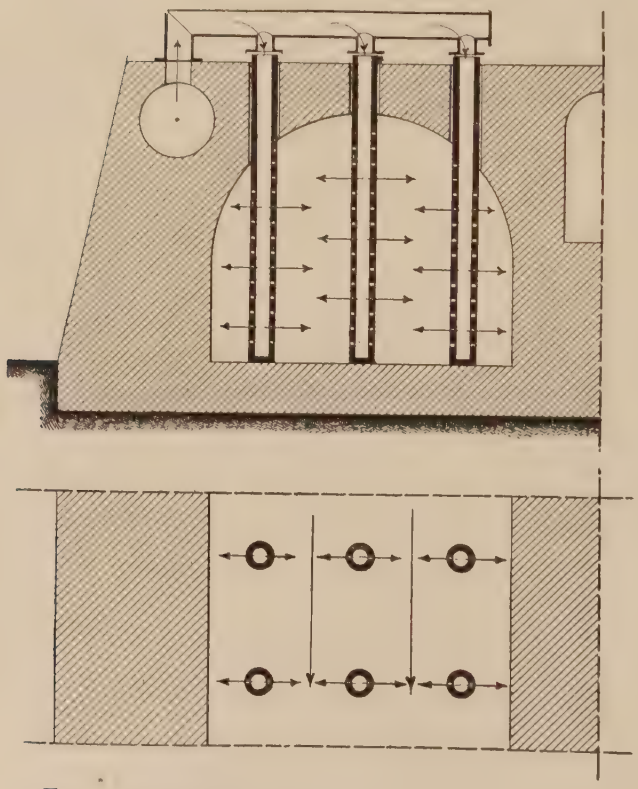

FIG. 170.—Gas Heating for Kilns with Continuous Firing.

used equally well, but only in the shape of logs. For the burning of the more delicate ware, glazed bricks, tiles, paving

tiles, etc., heating by gas can be employed. Different arrangements have been tried with this object, but the one that has given the best results, and which is nearly the only one used now, consists of introducing gas, in the place of the heating shafts, through firebrick pipes, called candles, as is shown in

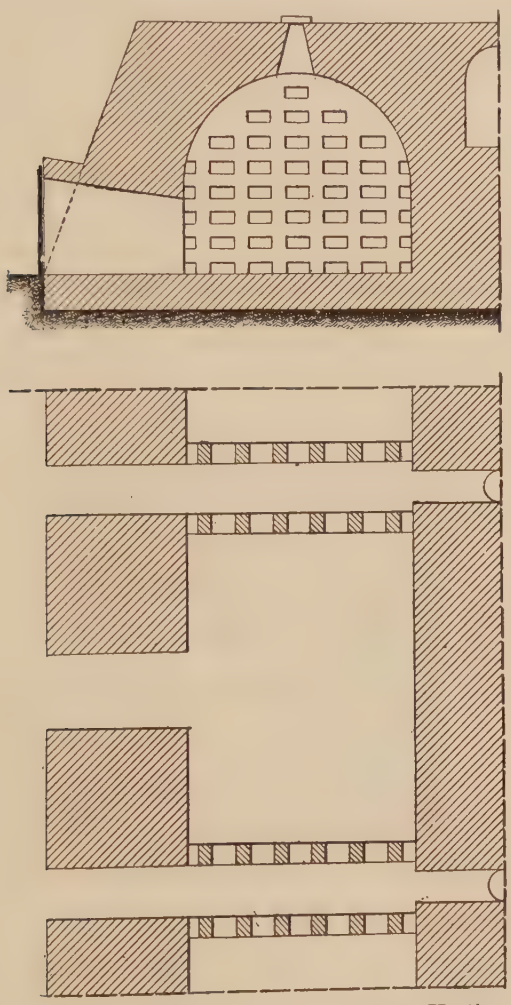

Fig. 171.—Kiln with Channels for Faggot Heating.

Fig. 170 (Society of Schwandorf, 1875). These are pierced with a great number of side holes, forming burners, throwing the flames perpendicularly to the current of air. The introduction of the gas into the pipes is through their upper part by means of a moveable iron pipe, which communicates with the

general gas channel built in the wall of the kiln. The gas is introduced simultaneously through several rows of candles, and the iron pipes are taken away in proportion as the fire advances (*see* also Fig. 262).

In the kilns with continuous firing which have just been described we have seen that the heating takes place in the middle of the objects to be burnt, the latter, if necessary, being more or less protected from direct contact with the flames by special methods of charging. There is a second type of

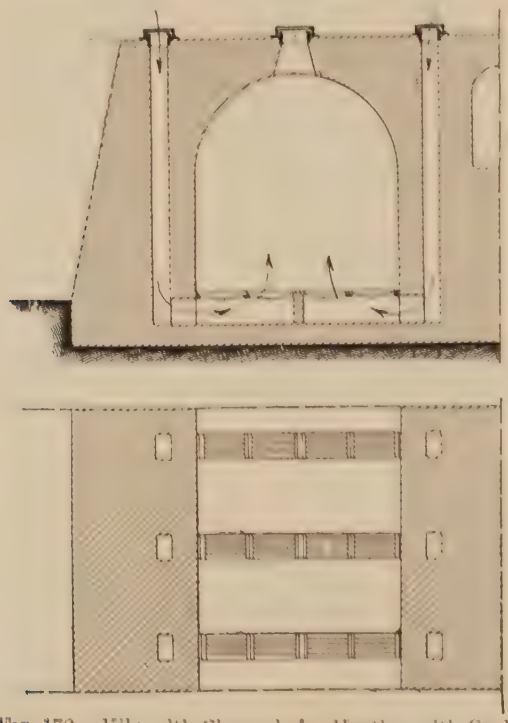

Fig. 172.—Kiln with Channels for Heating with Coal.

kiln with continuous firing, with one burning chamber, in which the heating is done by special furnaces, placed at regular intervals in the gallery for baking. This gallery is divided into a series of sub-divisions, from which the name of *channel kiln* has been given to it; historically, this is older than the preceding one (Arnold, 1839, Jolibois, 1852).

Kilns with channels give the best results for continuous burning when heated with faggots, straw, or other fuel of the same kind. Fig. 171 shows one of the arrangements that

can be used. The fuel is put in between two open-work walls, through an opening which is closed by a sheet of iron. The space enclosed between two furnaces forms a compartment which is emptied by a door that is blocked up during the burning. This door can also be used to put in the fuel, in which case one of the open-work walls ought to be knocked down at each burning. Generally it is then made of unburnt goods.

In the case of heating with coal, the solid hearth of the kiln, where the fireplace is, is replaced by a grating, the charging of the fuel being done either through a side door or through openings in the dome. Necessarily in that case a certain quantity of air must be allowed to enter under the grate. Fig. 172 shows an arrangement of this kind, fairly often used for tile burning (Gilardoni, Virollet). The grates are very narrow (23·62 in. to 27·95 in.), the charging of the fuel is done by a conical opening in the dome, and a certain quantity of air is allowed to penetrate, without any from the gratings, through vertical channels built in the side walls of the burning chamber (*see* also Fig. 263).

Heating by gas has also been used in the channel kilns by putting burners in the place of the grates, but this arrangement does not give as good a distribution of the heat as the one shown before in Fig. 170.

In continuous kilns the first phase of the burning, known by the name of smoking, ought, in a normal way, to be done in the general circulation of the gases before they come out into the chimney. This method has serious inconveniences when the body contains much water. In fact, at the commencement of the firing of a new compartment, the gases there cool so much that the steam which they contain condenses on the ware; not only is the body thereby much softened, but often deposits of the soluble salts, which arise either from the body itself or from the ashes of the fuel, are formed on the surface of the ware. In consequence of the action of the sulphurous vapours, sulphates are then formed, and these spot the ware. The remedy for this trouble is to first heat each compartment to a temperature of about 100° C. before starting it. This is done in the kilns of the first type

by means of movable furnaces, placed against the doors or above the openings for putting in the fuel. For very damp bodies it is better to use fixed furnaces, placed along the outside walls of the burning chamber, with channels under the bottom of the kiln. In kilns with channels the heating furnaces are used for this purpose.

If we compare the two foregoing types of continuous kilns, we shall easily see that the first has the most methodical and economical method of heating. Yet the kilns with channels are to be recommended for heating with wood (especially when in the form of faggots), and when it is desirable to burn exclusively such wares as fear the contact with the fuel. It is true that in this case heating by gas in kilns of the first type also gives a satisfactory solution of the problem.

**168. Continuous Kilns with several Firing Chambers.**—Burning in continuous kilns with only one burning chamber is very difficult when the ware is very delicate, especially for that which needs a high temperature, because it is not possible at each part of the burning to regulate the composition of the atmosphere in the kiln, and because the horizontal direction of the gaseous current is not suitable, or does not give a satisfactorily equal distribution of the temperature. In these cases it is better to use kilns that have several burning chambers which lead into one another.

The kinds of kilns of this class are very numerous; we can, however, divide them into three principal types:—

1. *Kilns with a gallery for burning, divided into several chambers by means of partitions, intended to modify the direction of the gaseous current.*—The characteristic arrangement of this type of kiln is shown in the longitudinal section in Fig. 173. Usually a horizontal damper, A, allows the chambers to be isolated. The heating is done by one of the methods already mentioned (wells for heating, grated furnaces, gas burners, etc.). The best distribution of the heat that we can expect to get by this arrangement may be obtained more simply in the kilns with a single chamber, by suitable methods of charging, and by placing movable dampers; this solution, however, is not a wise one.

2. *Kilns with separate burning chambers, of which there are several varieties, but which are usually of square or rectangular shape, placed side by side and grouped together, so as to form two parallel series, the outside chambers being joined together by two cross channels.*—The different systems of this kind of kiln are distinguished by the direction of the

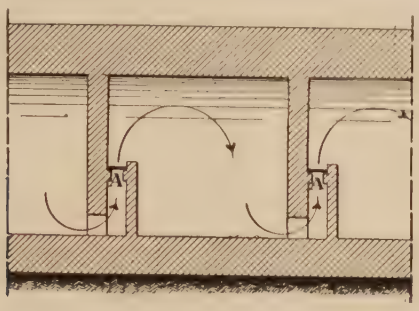

Fig. 173.—Kiln with several Burning Chambers.

gaseous current in each chamber and by the method of heating. It will suffice to mention the following arrangements, which are the most rational and those most used.

Fig. 174 shows the longitudinal section of a kiln heated by coal, by means of four furnaces placed at the four angles of

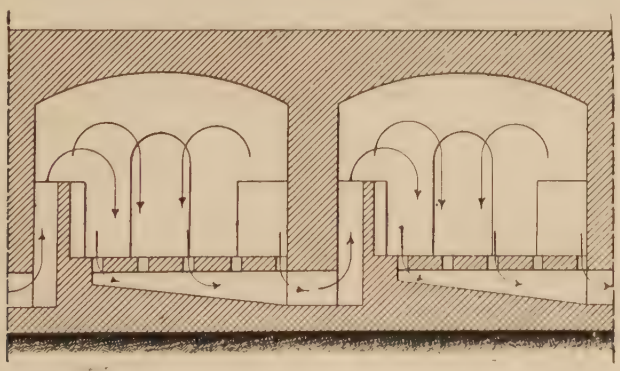

Fig. 174.—Kiln with several Burning Spaces.

each chamber; the draught is formed by openings spaced regularly in the bottom, which communicate with the following chamber through a network of flues; there is, as in channel kilns, a supply of outside air brought into the compartment that is being fired, independently of the general circulation. (The detailed drawing of this kiln is on page 689.)

Fig. 175 shows a kiln, heated by gas (Mendheim), having burners spread all about the bottom; the air from the preceding chamber, coming through a series of lower flues, rises vertically to descend along the wall of separation, and goes into the following chamber. (The detailed drawing of this kiln is on page 678.)

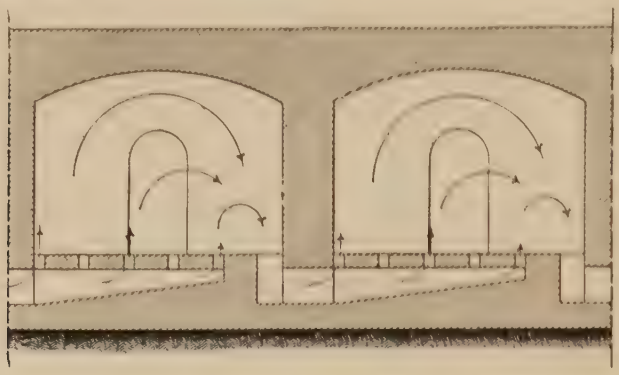

Fig. 175.—Kiln with several Burning Spaces.

Lastly, Fig. 176 shows a kiln that is also heated by gas, the latter coming in by burners placed in the dome, while the air, coming from the preceding chamber, ascends along the

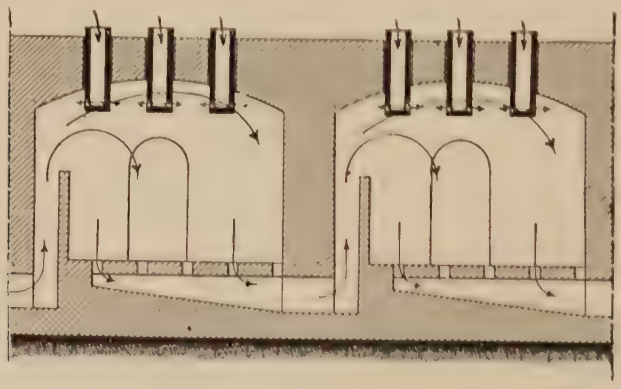

Fig. 176.—Kiln with several Burning Spaces.

wall of separation to descend again all across the chamber and passes out by openings spaced at regular intervals in the hearth into the following chamber.

3. *Kilns with isolated burning chambers, each one able to be heated separately as an intermittent kiln, or united at will with the one before and the one after it.*—Several systems

of this kind have been suggested, but, in spite of their arrangements, which were often very ingenious, in practice they did not possess the advantages that at first sight seemed to belong to them, because of their complications, and because of the loss of heat in the channels. They will, however, be mentioned again, *à propos* of the special purposes for which they can be used.

It may be useful to notice, at the end of these two articles devoted to continuous kilns, that seldom has a problem excited so much ingenuity on the part of inventors as that of the perpetual firing of pottery. Many ignore the necessities of the practical industry and make complicated theories, which, happily, are seldom carried out; others point out everywhere their system as the universal kiln, without taking into account that what is

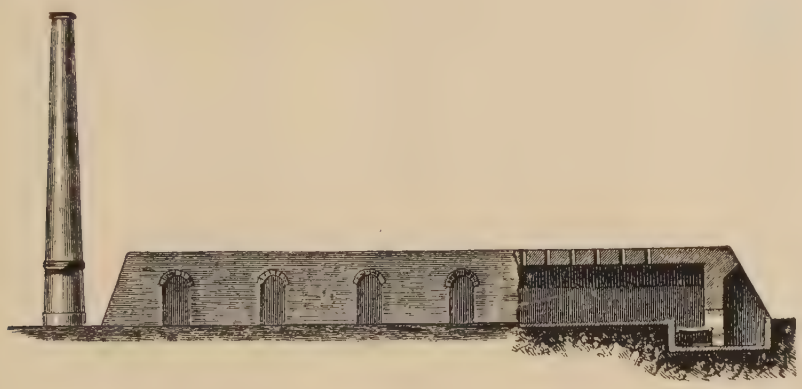

Fig. 177.—Semi-continuous Kiln.

good in one case may not be so in another. In fact, potters would do well to build only kilns which are quite suitable for the special conditions for which they are needed, avoiding complicated arrangements and systems that are good for everything.

**169. Horizontal Intermittent Kilns with several Fireplaces.**—The kilns of this class, which are often called by the name of *semi-continuous* kilns, are only portions of the kilns with continuous firing which have already been described. It is sufficient to build only a quarter, a third, or a half of them. The burning is naturally of an intermittent kind, but, during the period of firing, the working is almost the same as that of a continuous kiln.

Fig. 177 shows a kiln of this kind, taken from the type re-

presented in Fig. 168. At one end of the burning space are the fireplaces, arranged to start the kiln, while at the other is the communication with the chimney. In the same way, semi-continuous kilns with trenches, or with isolated spaces, can be constructed.

These kilns are used when the output of a continuous kiln would at that time be too great, if their enlargement in the future, or their transformation into a continuous kiln is foreseen. They ought, in any case, to be chosen in preference to intermittent horizontal kilns with one fireplace (Art. 166).

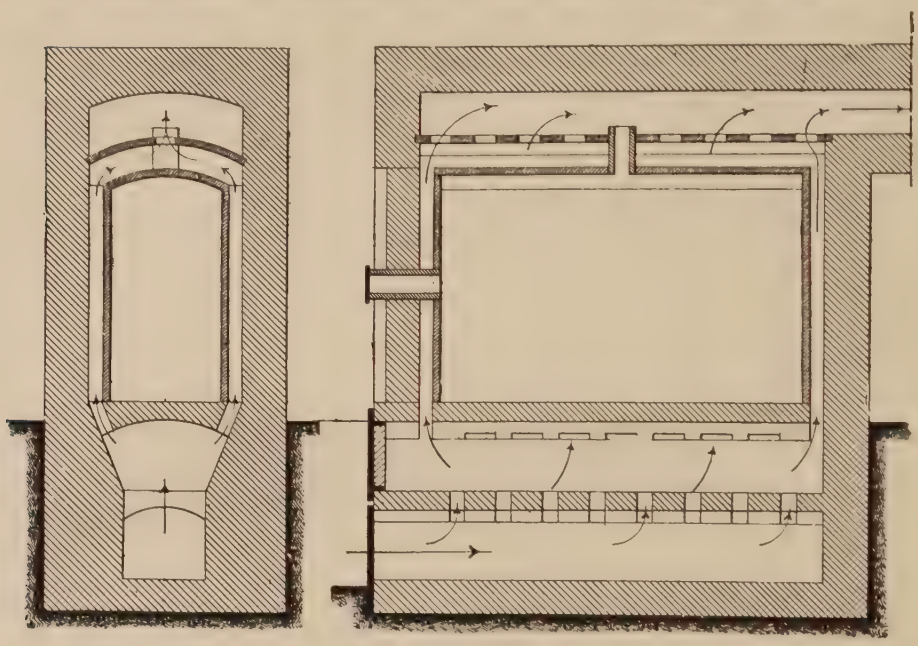

Fig. 178.—Muffle Kiln.

What has just been said concerning continuous kilns makes it unnecessary to explain them at greater length.

**170. Muffle Kilns.**—We have seen that in muffle kilns[1] the flames and hot gases do not reach to the burning space, and that this space is heated through the outside walls, the heat being transmitted to the ware by conduction and radiation. This arrangement is used for burning the wares which would be spoilt by contact with the flames, and which one does not wish

[1] *Fours à moufle.* From the English *to muffle*, to cover. This word, which the Dictionary of the Academy puts in the masculine, is used in the feminine by French potters.

to put in saggers. The considerable loss of heat which results from this method of transmission prevents muffle kilns from being used for firing wares which need a high temperature. A heat of 1,100° C. to 1,200° C. in the interior of the muffle is the highest that can be obtained in practice.

These kilns are generally arranged as shown in Fig. 178. The walls of the burning space are enclosed by slabs of fireclay, leaving between the latter and the outside walls a

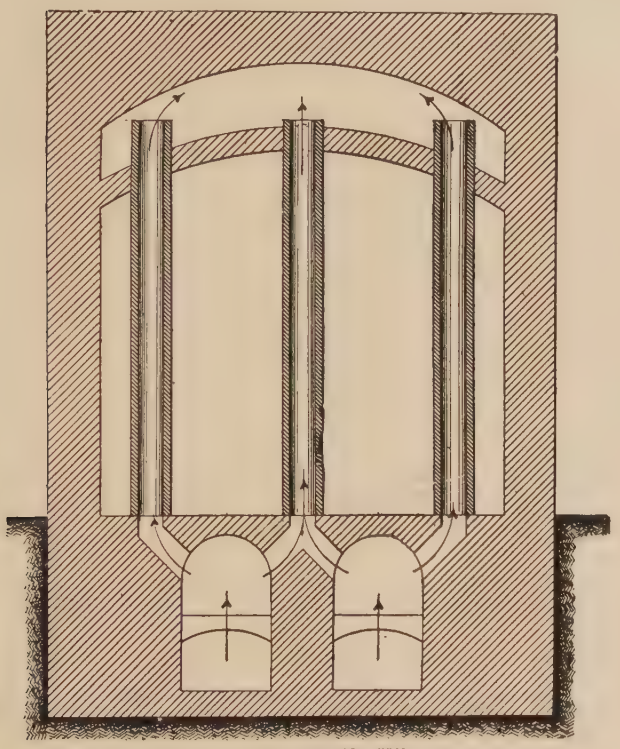

Fig. 179.—Muffle Kiln.

space through which the flames and gases circulate. The charging is done by a door in front, which is afterwards closed by a thin partition and a wall, keeping between them a space to allow of the even heating of this part of the kiln. An air-hole in the upper part allows the exit of the expanded air from the muffle, and a trial hole allows of watching the progress of the burning. The gases escape by an upper channel and pass into the chimney, which is usually connected with several kilns. The heating is done by means of fireplaces underneath, for wood

or coal, seldom by gas-burners. According to the ware to be burnt, the size of the space for burning varies from 2 ft. to 3 ft. 4 in., the height from 2 ft. to 6 ft. 6 in., while the depth is only limited by the practical length that can be given to the fireplace.

A second type of muffle kiln, which is not so often used, although, perhaps, wrongly so, is shown in Fig. 179. In this one the burning space is limited by the walls of the kiln, and the heating is done by vertical pipes, through which the flames pass. These pipes are arranged in parallel rows or in groups of five. The size of the burning space naturally may be much larger, because it is easy to manage the heating by several fireplaces side by side. The pipes in the middle are generally raised so as to facilitate the charging and emptying.

Usually these kilns, being intended for burning wares that are somewhat valuable, and the temperature never being very high, the consumption of fuel, which is relatively large, is yet not of special importance. It is only in certain factories with large output that intermittent burning has been attempted to be replaced by continuous firing.

To accomplish the latter, two parallel series of muffles are put side by side in such a manner that the warm gases pass from one to the other, the working being the same as that of continuous kilns with several burning spaces. The heating in this case is done preferably by means of gas blown in by a gas generator. The burners may be arranged, either at the lower part, as in the former examples, or at the upper part, with flames that descend along the walls of the muffle.

### (*d*) *Regenerators.*

**171.** We have seen that the best action of the chimneys was obtained by a temperature slightly above 100° C. If then the gases are passed out at a higher temperature, the excess of heat constitutes a loss, which we propose to lessen by using regenerators [1]. These may be for intermittent or continuous working.

[1] Fr. *Récupérateur*. The word *régénérateur* is sometimes used as well, but this expression is not good, because it does not work by regenerating, but by recovering the heat.

Intermittent regenerators (Siemens) are formed by two or more chambers, filled with a pile of bricks, which are placed between the kiln and the chimney. While passing through one of these chambers the gases yield up part of their heat to the bricks, until the temperature of the latter is so high that, the regeneration becoming less and less, it is advisable to make the gases pass through a second space. The heat accumulated in the first can then be used for heating a current of air which is carried in an opposite direction to the preceding current of gas. Regenerators of this kind, which have been of great use in glass making and metallurgy, have not been much used in pottery, where continuous regenerators are preferred to them.

These continuous regenerators may be various in the methods

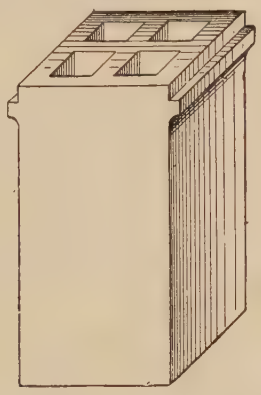

Fig. 180.—Brick for a Continuous Regenerator.

of construction, but they are always composed of tubular fire-bricks, placed in such a manner that they can be passed through in one direction by the gases coming from the fire and in another by the air to be heated. Fig. 180 (Gaillard and Hallot) represents a tubular brick of this kind, and Fig. 181 shows the manner in which they are put together to form a continuous regenerator. The warm gases enter by A, and follow the path ABCDE, to pass out into the chimney. On the other hand, the cold air enters by F, and rises into the holes of the bricks, and passes out warm into another chamber, G. Stoppers allow of cleaning the horizontal channels. The difference in the temperature between the gases coming in and the hot air is usually from 150° to 200° C. By making the regenerator large

enough, the limit can be reduced to the heat desired for the gases as they pass out by the chimney.

Regenerators naturally can only be used in pottery with kilns for intermittent firing, the kilns for continuous firing only giving off gases that have the temperature which is exactly sufficient to ensure the draught in the chimney. As for the hot air made in the regenerator, it can be used either for drying the moulded ware or the raw materials, or for beginning the heating of another kiln, or lastly, in the case of heating by gas, it may supply the secondary air which is necessary for the combustion in the kilns.

We must notice, on the subject of this last use, that re-

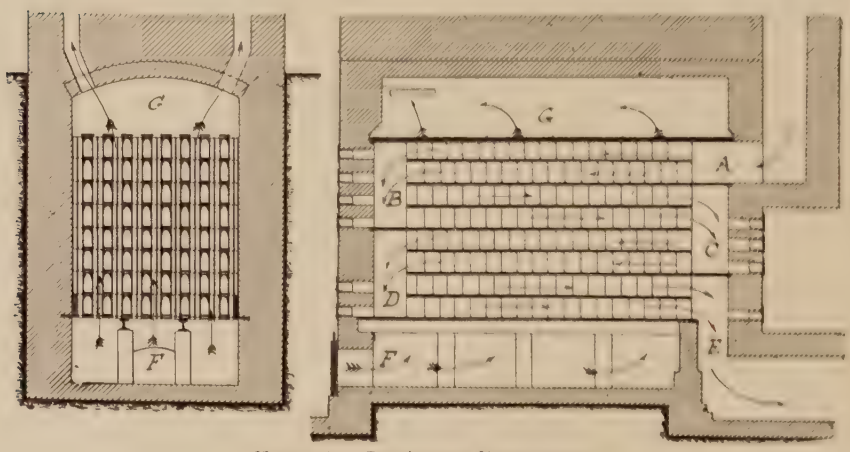


Fig. 181.—Continuous Regenerator.

generators absorb a large quantity of heat before attaining their normal working, so that it may happen that they are only efficacious when the baking is nearly finished, that is to say, when they are not needed any longer. They must then be used either for heating the air intended for another kiln, or else be very slightly built, so as to be less powerful when they are joined to a single kiln.

### (*e*) *Construction of Kilns.*

**172.** In spite of the diversity in kilns used in the ceramic industry, there are, however, certain general rules for construction that perhaps it would be wise to repeat at the end of this paragraph, devoted to the description of the kilns. The

first condition which all kilns ought to fulfil, the enunciation of which sounds a truism, is that they must *bear the temperature* to which they are subjected and also the action of the flames and gases from the fireplaces. This condition is nearly always easy to accomplish in pottery. It is sufficient to make the walls of the burning space with ware having the same power of resistance to the fire as that which is burnt in it. We can understand, in fact, that these walls never have to bear a greater heat than that to which the goods, with which they are charged, are submitted. This observation, naturally, does not apply to muffles, which ought always to be made of very good fire-bricks. The same applies to those parts of the masonry that are near the fireplaces, as these have besides to resist the destructive action of the ashes.

It is often more difficult to obtain materials that will well stand the action of a large number of successive heatings and coolings. But this question will be discussed with the changes that take place when speaking of the special manufacture of fireclay goods (Chapter X.).

The second condition that kilns ought to fulfil is *to resist the alteration of form* caused by the expansion of the masonry under the influence of heat. In fireclay goods of good quality this expansion is $\frac{1}{250}$ to $\frac{1}{200}$ at a temperature of 1,000° C. It is greater in ordinary terra cotta. The result is that the inner walls of the kiln, being more strongly heated, by increasing in volume during the burning, force the outer walls, which do not expand, to get out of shape and to crack. This inevitable action has no serious consequence if, when the kiln has cooled, the cracks close up again and if all the masonry returns to its original shape. But it is another thing if the changes are permanent. With each new burning they increase speedily, necessitating repairs which are always unsatisfactory, and end by completely ruining the solidity of the kiln.

These inconveniences are remedied either by strengthening the kiln, or by separating the inner walls from the outer ones. According to the special case, one or other of these means is used, and sometimes both at the same time. Round kilns are

easily strengthened by means of iron hoops, tightened by wooden wedges. From this point of view, kilns of this shape are always to be preferred. The strengthening of flat walls and angles is done by means of upright iron or wooden supports, bedded in the ground and joined at the upper part by means of iron tie-rods, the tension of which is regulated by bolts. The separation between the inner and outer walls is by a layer of cinders or sand that is not clayey. In this case the outer walls ought to be so arranged that the action of weight should bring them back to their original position. This method is specially employed in continuous kilns, which by their large dimensions would require very costly strengthening.

It is equally essential to avoid, as much as possible, *the escape and entrance of air*, which interfere with the regular working of kilns. These may be caused either by displacement of the masonry or by its porosity. As to the first case, we must observe that if, by one of the two methods already mentioned, alterations in the exterior shape can be prevented, it is not the same with those which may be caused in the channels and interior flues. That is why it is best to avoid all complicated channel schemes, all channels put in projecting parts, such as vaults, with great expansion, all walls that are too thin, etc. Many kilns which on the plans have a very ingenious method of working give bad results at the end of a short time because all the channels lead into and communicate with one another.

As to the porosity of the masonry, one knows that walls, even when very thick, easily let air pass, and if ever so little, the lowering of the kiln would become important. When the surface of the walls through which air may penetrate is large enough, it is necessary to prevent this porosity by a layer of cinders or fine sand spread between the masonry, or by covering their outer surfaces with a glaze.

Lastly, we must still mention the necessity of *protecting kilns against damp*. This recommendation also seems a truism, but we think it necessary to give it, because we have ascertained that many kilns work badly because, being built on damp or permeable ground, the water from the subsoil, drawn up by

capillarity, cools the lower parts and prevents the burning of the ware in them, or even forms steam, thus spoiling the draught.

## § 3. Working of the Kilns.

**173. General Remarks on the Working of Kilns.**—Whatever may be the nature of the ware to be burnt and the type of kiln employed, the burning includes five operations:—

1. *The charging*, that is to say, putting the ware into the kiln;

2. *Smoking*, which consists in heating the ware to a temperature of about 100° C.;

3. *The burning properly so called*, which is most usually subdivided into slow firing, full fire, and annealing;

4. *Cooling* the ware in the kiln;

5. *Emptying*.

The general consideration of these five operations will be followed by the consideration of *the thermic yield of kilns*.

**174. Charging.**—Three usual methods of charging are described, the choice of which depends upon the nature of the ware.

For strong and not vitrified ware, that is to say, ware which does not soften in burning, *charging the kiln itself* is used, the objects being piled on one another in such a manner as to fill as full as possible the space for burning. The only condition is to leave, while charging, the spaces that are necessary for the circulation of the flames and gases to spread the heat uniformly. Fig. 143 shows the manner of charging plain bricks in a continuous kiln, and other examples can be found in the chapters relating to the special industries. Usually this method of charging is applicable to all terra cotta and certain kinds of stoneware. It is sufficient to put the more fragile goods, which usually need less heat, in the upper parts, which are less full, and further from the fireplaces. Charging open is only applicable to wares which do not suffer from the contact of the flames, at least if the burning is not done in muffle kilns, which is usually less economical. As to glazes, these can hardly be burned in the open unless they only partially cover the goods, and then only the plain surfaces may be in contact. In this case they are burnt in muffles, because it is very seldom that

they can bear the direct action of the flames without detriment. When there is any fear that certain bodies will soften and stick together, they can be powdered over on their points of contact with quartzose sand which remains fireproof at the temperature for baking the ware.

*Charging with quarries or slabs* is employed for fragile and vitrifiable wares, or those which are covered with glaze. This is done either in ordinary kilns or in muffles, according as the ware can or cannot be exposed to the flames. In theory, it consists in putting in the burning space a scaffolding of strong ware, or of fireproof pieces, in such a manner as to form a series of cases in which is placed the ware. Fig. 182 shows an example of this kind of charging, in which A represents the walls of the kiln, B small columns of fireclay, and C slabs that are also fireproof. The latter are perforated in such a

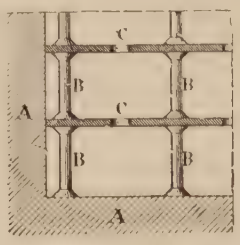


FIG. 182.—Charging with Quarries or Slabs.

manner as to allow the gases to circulate. The goods rest on these slabs on a face which is not covered with glaze. For certain goods the vertical columns are left out, only covering each horizontal layer of goods with slabs which are then used simply for the purpose of levelling the partitions of the charge.

*Charging in saggers* is done, on the one hand, for unglazed, non-vitrifiable ware, which suffers from the action of the flames, but which need not be burned in the muffle, and also for glazed wares, and for those which are liable to get out of shape by the action of heat.

Saggers are fireclay receptacles of various shapes and dimensions, which it is wise to enamel inside when it is intended to burn glazes in them. They are often given the form shown in Fig. 183, by placing them one on the other, in piles, the extreme members of which have flat bottoms, and by putting

between them rolls or "wads" of thin fireclay, which are crushed under the charge, and serve at the same time to join them together and to make them firm. The diameter of the saggers varies according to the size of the objects; sometimes they are made oval, more rarely square or rectangular.

Putting the ware in place in the saggers is called *placing*. If the body is unglazed and non-vitrifiable, it is placed in the inside of the sagger, piled up, and a fireclay slab from time to time is put on the inside ledge of a sagger (Fig. 183), thus dividing the pile into a series of cases, placed over one another, so that the lower goods do not bear the whole charge. This arrangement, besides, is indispensable when the objects are of such a shape that one cannot put them in a pile.

If the bodies are covered with glaze, the objects are stood

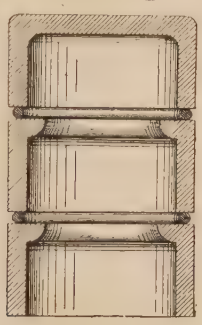

FIG. 183.—Saggers.

on their bottom or on an unglazed part (vases, pots, etc.), but as they cannot be put in a pile, because the fusion of the glaze would make them stick together, it is necessary to burn each of them in a separate case. Under certain conditions, however, it is not necessary to divide the pile of saggers into real cases, it is sufficient to place in holes pierced in the outsides of the saggers small supports, on which the object can rest. The sharp top of these supports prevents the glaze from sticking too much, and leaves when burnt only a slight mark. In the same way very light goods can be piled one on the other, by separating them with small fireclay pieces (stilts), which only come in contact with the ware at points, thus producing only a little prick on the glaze. In Chapter XI. will be found examples of these latter methods of charging, which are especially used for faience.

When the bodies become soft the difficulties of charging are much greater, because it is necessary to try and prevent them from becoming misshapen. The objects can no longer rest only on spikes or points, and ought necessarily to be charged each one separately in a case, formed on one side by saggers, and on the other by other fireclay pieces, which are of a suitable shape. This method of charging, peculiar to porcelain, will be described more in detail in Chapter XIII.

From the foregoing it will be seen that the methods of charging are very various, and that it is difficult to give other general notes on this subject than those already given. We may only add that, after having taken all the precautions needed for the special nature of the ware, after having reckoned for the good circulation of the flames and gaseous currents, we must try, so as to economise fuel, to put the largest possible quantity of ware into the burning space.

**175. Smoking.**—Smoking, sometimes called by the very improper name of stoving, is an operation, the object of which is to evaporate the water contained in the body, the glaze, the pieces used for charging, and, finally, the walls of the kiln. It is finished when the burning space is at a uniform temperature of about 100° and when the gases passing out of the chimney no longer contain steam.

This operation, which is very simple when the ware is thin and comparatively dry, becomes a much more delicate one when the objects are thick and damp. In fact, there must be evaporation but no bubbling, so as to avoid steam being formed in the ware, which would make it split. On the other hand, it is wise to avoid as much as possible the steam that is given off from those goods that are near the fireplaces condensing on the ware that is further off, while still cool, to prevent them softening and also the spots thus caused, which have been mentioned before. For this purpose, the steam that is formed must be got rid of as quickly as possible, which is not always easy in kilns with descending or horizontal flames, because the steam, being lighter than air, has a tendency to accumulate in the upper parts of the burning space. In theory it is wiser to make as much use as possible of an ascending draught for this operation.

The fuel used ought to be dry, with a slow, regular combustion and not much flame. Hard, dry wood and coke give the best results. The proportion of air that enters the kiln ought to be large, and is gradually reduced as the temperature increases, but the object of this heating ought always to be to obtain moderately warm air, and not to raise the temperature of the kiln.

As for apparatus to control it, mercury thermometers are used which are graduated up to 200° C. or 250° C., and iron rods, that are plunged through the trial holes into the different parts of the burning space and then drawn out again at the end of some moments. The height of the temperature shows the progress of the heating, and the bubbles which settle on the cold iron rods allow of the proportion of damp still contained in the corresponding part of the kiln being ascertained. It is only when the rods come quite dry out of the trial holes that are furthest from the fireplaces that the smoking may be reckoned as finished.

**176. Firing Properly so Called.** — This operation lasts from the end of the smoking to the moment when the ware has reached the highest temperature to which it has to be subjected. It can be divided into three stages, which are more or less distinct.

*Slow firing*, in which the temperature rises to about 500° C. to 600° C., that is to say, until the time when the hydrosilicate of alumina is decomposed. This stage needs a slow and gradual heating.

*Full fire*, beginning at the foregoing temperature till it reaches that of the baking, and characterised, on the contrary, by a quick and sharper heating.

Lastly, *annealing*, a stage of variable length, according to the thickness of the ware and the method of charging. During this period, the necessary temperature having been reached, it is wise to keep it the same until the centre of the ware has been penetrated by it.

The manner in which the baking is done depends entirely upon the nature of the ware, the type of kiln used, the method of heating, and on the quality of the fuel. Some remarks on this subject have already been given in the first paragraph of this chapter; others will be found *à propos* of the different special

industries; but it is necessary to study exactly, in a general way, the questions which relate to the composition of the atmosphere of kilns, to the measuring of the draught and to that of the temperature.

**177. The Atmosphere in the Kilns.**—We have already seen (Art. 147) the influence that is exerted on the burning of the bodies and glazes by the composition of the atmosphere of the kilns.

We know that this atmosphere is *oxidising* when the combustion takes place in an excess of air, and when consequently there remains some free oxygen. The normal composition of the air by volume is 21 per cent. of oxygen and 79 per cent. of nitrogen, or by weight 23 per cent. of oxygen to 77 per cent. of nitrogen. Consequently, if in the gases coming out of the kiln there remains 10·5 per cent. of oxygen by volume, or 11·5 per cent. by weight, then the combustion has been carried on with a quantity of air double of what was strictly necessary. This proportion corresponds to the most oxidising working that is employed in pottery kilns.

The atmosphere is *neutral* when it contains neither oxygen nor combustible gases. If the combustion takes place with pure carbon, the atmosphere in this case would contain 21 volumes of carbon dioxide to 79 of nitrogen. But as in fuel there are always hydrogen and hydrocarbons, the combustion of which produces steam, and as, on the other hand, there always remain traces of oxygen and carbon mon-oxide, the proportion of carbon dioxide scarcely rises above 18 per cent. or 19 per cent.

Lastly, the atmosphere is *reducing* when there is an excess of combustible gases—carbon mon-oxide, hydrogen, hydrocarbons—when all the oxygen has naturally disappeared, and the proportion of carbonic acid is below the limit that has just been mentioned.

The composition of the atmosphere in the kilns depends on the arrangement of the fireplaces, on the nature and method of charging the fuel, and, finally, on the draught. An oxidising working can easily be obtained in all fireplaces, by putting comparatively little fuel and having a strong draught, and introducing a great deal of air. On the contrary, a decidedly reducing working needs a thick layer of fuel, a small draught, and also a small quantity of air; only furnace fireplaces and heating by gas can produce it with a normal working.

By referring to the fireplaces shown in Figs. 140, 141, 143, 144 and 145, it can easily be seen that the periodical charging of fuel each time lowers the working of the fire. In the same way in the furnaces of steam boilers there is, immediately after each charge, a considerable giving off of combustible gases, which are only partially burnt, as may be seen by the black or red colour of the smoke. At the end of several moments the combustion becomes complete, then air is in excess, until the time when a new charge causes the same disturbance. A very methodical heating, with chargings at very short intervals, as is done in kilns with continuous firing, decreases these irregularities, but without getting rid of them. Generally, so that the fireplaces of this kind may work well, they ought to have a decidedly oxidising working, which only becomes neutral or even reducing for some instants after each charging.

It is not the same with furnace-bar fireplaces (Figs. 142, 148, 149 and 150), the charging of which, when well done, ought only to cause slight changes in the working. The latter is more affected by the periodical clearing of the grates, which, by reducing the resistance to the circulation of the gases, gives a constant draught, and causes a variation in the weight of the air that enters the fire. Yet, as the clearings are less frequent than the chargings, it is usually possible to manage them in such a way as not to be obliged to clear them during certain periods of the burning. In furnace-bar fireplaces it is easy to regulate at will the thickness of the layer of fuel, and, consequently, the composition of the atmosphere of the kiln. The inconvenience of them, as has been already noticed, is that they lend themselves rather badly to the production of a moderate heat, such as is necessary during the slow firing. The thickness of the layer of fuel which is suitable for different workings depends on the nature of the fuel, on its size, and the proportion of ashes and clinker in it. The larger the pieces and the purer the fuel, the thicker the layer ought to be. In a medium one with coal, a thickness of 12 in. to 16 in. gives a neutral atmosphere, a less thickness makes it oxidising, while with a greater thickness it becomes reducing.

Heating by gas has not these inconveniences, and gives a

regular composition of the atmosphere of the kiln and one that is easily regulated at will, but only when the working of the gas generators is itself very regular, which is seldom the case except in blast gas generators.

We may say, therefore, that it is impossible to obtain in the kilns, not only during the whole of the burning, but even during a sufficiently long space of time, an absolutely regular atmosphere. We can only try by a good arrangement and a rational management of the fireplaces, to reduce the errors to the narrowest limits.

If the temperature of the burning is low or medium, it is easy enough to manage the heating with a decidedly oxidising or reducing working. But that is not so if the temperature has to be very high, the introduction of a large excess of air or an incomplete combustion having the effect of lowering to a great extent the temperature of the gases passing out of the fireplaces. In that case it then becomes almost a neutral working, and does not leave in the atmosphere of the kilns more than the excess of oxygen or of combustible gases that are strictly necessary to act upon the ferric oxides.

There is another consideration which in many kilns necessitates a somewhat neutral working during the full firing. That is the necessity of making the flames of sufficient length for them to reach right across the burning space. When the combustion takes place with a large excess of air, the flames are made shorter than if the proportion of air were what is strictly necessary. In that case, the combustion is only due to the burning of the gases that circulate in the middle of the charge, and the temperature more easily becomes uniform in all the burning space.

Finally, there is still one point that has sometimes a certain importance when charging with saggers, that is, the various speeds with which the different gases can pass through a wall of fireclay that is always porous. All things being equal, if we call 1 the *speed of diffusion* of the air, oxygen alone has only a speed of 0·949, while it is raised in combustible gases to 3·800 for hydrogen, 1·015 for carbon mon-oxide, 1·344 for saturated hydrocarbon, and to 1·019 for unsaturated hydrocarbons. It

follows that the atmosphere inside the saggers has a tendency to be more reducing than that which fills the burning space.

**178. Analysis of the Gases.**—The determination of the composition of the atmosphere of a kiln may be made by the direct observation of the flames and gases passing out of the chimney, by the chemical analysis of them, and, lastly, by measuring their density.

However primitive and uncertain the method of direct observation may be, yet it is, except in certain special cases, the only one that is actually used. It is based on the following signs: When the flames are short, brilliant, with clearly marked edges, and when their extremity ends in a point that is easily noticed, then the working is oxidising. If, on the contrary, they are long, cloudy, with uncertain edges, their extremity dying out, to be followed by a smoky ending, the working is reducing. If the gases coming out of the chimney have a bluish colour, even sometimes coloured black, but only at the time of charging, then it is a sign that the combustion is moderately complete. If, on the contrary, the colour is constantly yellow or red, with a black colouring after the charging, then the combustion is incomplete.

These observations may suffice, in the majority of cases, for practical uses; but it is no longer so when it is required, at certain moments of the burning, to obtain an atmosphere of a specified composition. Then we must have recourse to chemical analysis. For this purpose the Orsat apparatus is used, or that shown in Fig. 184, constructed by M. Coquillon, which is taken from the former. A glass tube, M, or measurer, surrounded by water to keep the temperature constant, is divided into a hundred equal parts to a cubic centimetre; in the lower part, of a less diameter, the graduation is made in tenths of a cubic centimetre. This is finished by an india-rubber tube joining the apparatus to a flask containing water. The upper part is joined to a capillary tube, R, finished at one end by a tube, *t*, for the introduction of the gas, at the other by a bell, E, and this communicates besides with four receptacles: P′, containing potash; P, pyrogallate; C, cupric chloride, and B, which is a burner surmounting the bell C′. All the communications with tube R being

closed, the measurer is filled with water by raising the flask; then, after having put tube *t* in connection with the atmosphere to be analysed, the flask is lowered again, so as to fill the measure exactly with 100 cubic centimetres of gas. After having closed tube *t*, the communication with the receptacle P is opened, into which the gas is forced by raising the flask. In a few moments the gas is passed back into the measurer, by again lowering the flask, and the new volume is read on the graduated scale, the difference showing the proportion of carbon dioxide. It is continued in the same way by making the gas pass

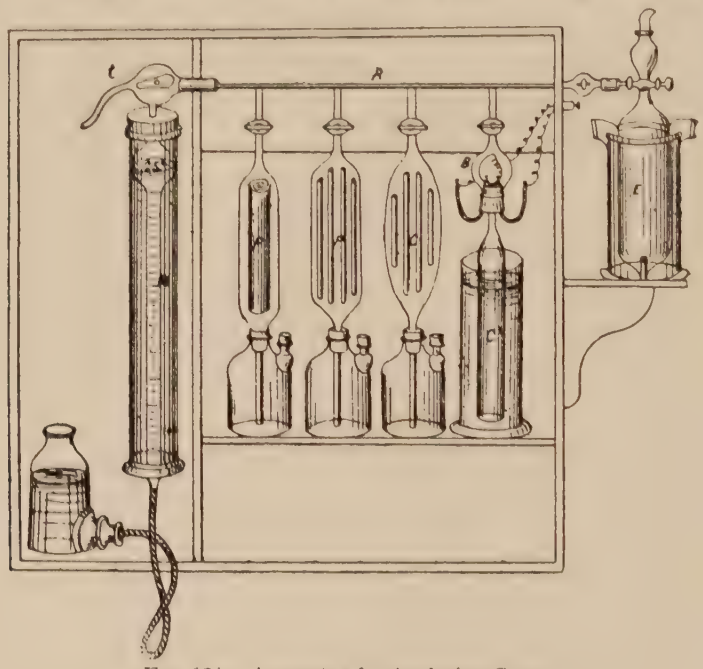


Fig. 184.—Apparatus for Analysing Gases.

into the reservoir P, which absorbs the oxygen, into C, which takes the carbon mon-oxide, into E, in which are added some drops of bromine, thus retaining the unsaturated hydrocarbons, and lastly into B, where, by the addition of a definite quantity of oxygen, the hydrogen and saturated hydrocarbons are fired by an electric current. The volume of carbonic acid produced, and afterwards absorbed in the receptacle P, indicates the proportion of protocarbonate of hydrogen, and the contraction of the volume shows the proportion of hydrogen. The remaining gas is nitrogen.

This full analysis, when applied to the combustible gases produced in the gas generators, gives accurate indications of the gas manufactured. For the gases for burning, it is usually simplified by merely determining the proportion of carbon dioxide, oxygen and carbon mon-oxide. We think that, except for scientific research, this shortened analysis is preferable, as it can be done in a few minutes; besides, the variations in the composition that are shown by the gases during the progress of a burning make the undertaking of a lengthy analysis quite delusive. This is only done with continuous kilns that are in good working, and yet the method of three or four short consecutive analyses is preferable to the results of one single complete analysis.

It is known that the density of carbon dioxide is considerably greater than that of air (1·529); by measuring the density of the gases of combustion, then, it is possible to reckon indirectly the proportion of carbon dioxide which they contain, and, consequently, deduce from that the composition of the atmosphere of the kilns. Two apparatus have been invented on this principle, which, thanks to the constant circulation of the gases of combustion, show continuously on a dial the proportion of carbonic acid. One of them, constructed by MM. Meslans et Frére, is a kind of hydrostatic balance, the beams of which bear two balls, one plunged in air, the other in the gas to be analysed. The difference in weight of the fluid displaced by each of the balls makes the balance lean more or less. The other, invented by M. Arndt, known by the name of an econometer, is likewise a balance, also carrying two balls, but one of these contains air and the other the gas, which, by a special arrangement, can be automatically renewed. The common defect of these apparatus is their extreme sensitiveness, so that the least dust, or the slightest impurity of the gases, makes the results false. Besides, they are only applicable to kilns which have a constantly oxidising working, because, all the combustible gases being lighter than air, it becomes impossible to draw any conclusion from the density of the gaseous mixture in which they are found even in a small proportion.

**179. Measuring the Draught.** — The draught is regulated

according to the intensity that is desired for the fire, the length of the flames and the composition of the atmosphere. Direct observation is nearly always sufficient for practical men to suitably regulate the position of the dampers. Yet it is advisable to measure the depression caused by the chimney; if the results thus obtained are in themselves of no great value, they help in any case by making it easier to carry on the later burnings by the observations made in the first operation.

The different apparatus which are used for measuring draught are very simple, all giving very good results, but the apparatus shown in Fig. 185 is the one actually preferred. It is composed of two flasks, having a section ten times bigger than the U tube that joins the ends of them. One is joined by an india-rubber tube to the part where the measurement of the depression is desired, and the other is open to the atmosphere by a glass tube, intended to prevent dust from getting in. They are filled with two liquids, chosen in such a way that they do not act on one another, and having densities that are sufficiently at variance not to mix together, for example, water and phenol coloured black. They are so arranged that the surface of the separation of the liquids is opposite the zero of a scale, the position of which can be altered to suit. The depression that takes place in one of the flasks causes a difference of level which is multiplied by ten in the U tube, so that the draught measured by a difference in height in millimetres of water is shown as centimetres on the graduated scale.

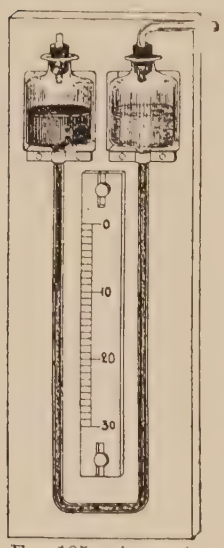

FIG. 185.—Apparatus for Measuring Draught.

The india-rubber tube fixed to the apparatus is finished at its other extremity by an iron or copper tube, which is put into the kiln between the burning space and the draught damper.

**180. Measuring the Temperature.**—The temperature of the kilns can be observed by the eye, according to the colours that the ware or the walls of the kiln become. In this case

the results shown in the following table, laid down by Pouillet, are generally adopted:—

| | Degrees C. |
|---|---|
| Red beginning | 525 |
| „ dark | 700 |
| Cerise beginning | 800 |
| „ „ | 900 |
| „ bright | 1,000 |
| Orange dark | 1,100 |
| „ bright | 1,200 |
| White „ | 1,300 |
| „ dull | 1,400 |
| „ shining | 1,500 |

In order to be fairly accurate, it is indispensable that the observer should first be in the dark, so that, by daylight, his eye may not be influenced by the varying brightness of the sun's light. Then the shade of the inside of the kiln can be fairly easily recognised, if the atmosphere is not disturbed. When this atmosphere is a reducing one, then the observation is more difficult. It is also advisable not to allow oneself to be influenced by the brightness of the flames, which are white when hydrocarbons are burning, and blue when they are only produced by carbon dioxide or hydrogen. In any case, the foregoing results are too high; the orange tints appear after 1,000° C. and the white ones after 1,200° C., it is wiser therefore to go only by the colour noticed, and not by the temperature, according to the foregoing table.

In kilns, the charging of which is done open, the advance of the burning can also be reckoned by the *shrinkage*, that is to say, by the height to which the mass that is charged has been lowered. In this case, evidently it is not done by measuring the temperature, but only by determining whether a certain degree of burning, which has been decided by experience, has been reached. This observation is made by means of an iron rod, on which is measured the distance between a fixed point in the kiln and the upper part of the charged ware.

For all baking of pottery that needs a certain exactness, the *pyroscopes* are used to determine whether the temperature necessary for the burning has been reached. Mostly *tests* are

used for this purpose; these consist of specimens of the body, covered, when needed, with glaze; they are put into the kiln through special sight-holes, and are afterwards drawn out during the burning to find out whether the body has attained the suitable hardness or colouring, or else to see whether the glaze has vitrified. When the last test taken out has proved that the burning has reached the desired state, it is still necessary to continue the firing for a certain time, which is regulated by experience, so that the goods, which are usually thicker or more protected than the tests, should also reach the same degree of baking.

At the same time as the tests certain *metals* can be put into the kiln; these melt and volatilise at specified temperatures. The following table shows the materials which can be used thus, and the temperature that corresponds with their change of state:—

| | °C. |
|---|---|
| Tin, fusion | 233 |
| Lead ,, | 325 |
| Zinc ,, | 433 |
| Aluminium, fusion | 625 |
| Zinc, volatilisation | 930 |
| Silver, fusion | 954 |
| Gold ,, | 1,045 |
| Copper ,, | 1,054 |
| White pig-iron, fusion | 1,130 |
| Grey ,, ,, | 1,220 |
| Nickel, fusion | 1,410 |
| Palladium, fusion | 1,500 |
| Platinum, ,, | 1,775 |

The observations made with these metals are usually falsified by the layer of oxide that is formed. Now, it is preferable to replace them by pyrometric tests, which have been specially studied by Seger. This potter has made a series of tests, the composition of which is shown in the following table, as well as their order number. In this table, $Na^2O$ represents soda, PbO plumbic oxide, $AL^2O^3$ alumina, CaO lime, $Fe^2O_3$ peroxide of iron, $K^2O$ potash, $SiO^2$ silica and $Bo^2O^3$ boracic acid:—

| Order Number. | Composition. | | | | |
|---|---|---|---|---|---|
| 022 | $0{\cdot}5Na^2O$ — | $0{\cdot}5PbO$ — | $0{\cdot}0Al^2O^3$ — | $2{\cdot}0SiO^2$ — | $1Bo^2O^3$ |
| 021 | ,, | ,, | 0·1 ,, | 2·2 ,, | ,, |
| 020 | ,, | ,, | 0·2 ,, | 2·4 ,, | ,, |
| 019 | ,, | ,, | 0·3 ,, | 2·6 ,, | ,, |

| Order Number. | Composition. | | | | | |
|---|---|---|---|---|---|---|
| 018 | $0{\cdot}5Na^2O$ — | $0{\cdot}5PbO$ — | $0{\cdot}4\ Al^2O^3$ — | $2{\cdot}8SiO^2$ — | $1Bo^2O^3$ | |
| 017 | ,, | ,, | 0·5 ,, | 3·0 ,, | ,, | |
| 016 | ,, | ,, | 0·55 ,, | 3·1 ,, | ,, | |
| 015 | ,, | ,, | 0·6 ,, | 3·2 ,, | ,, | |
| 014 | ,, | ,, | 0·65 ,, | 3·3 ,, | ,, | |
| 013 | ,, | ,, | 0·7 ,, | 3·4 ,, | ,, | |
| 012 | ,, | ,, | 0·75 ,, | 3·5 ,, | ,, | |
| 011 | ,, | ,, | 0·8 ,, | 3·6 ,, | ,, | |
| 010 | $0{\cdot}3K^2O$ — | $0{\cdot}7CaO$ — | $0{\cdot}2Fe^2O^3$ — | $0{\cdot}3Al^2O^3$ — | $3{\cdot}50SiO^2$ — | $0{\cdot}5\ Bo^2O^3$ |
| 09 | ,, | ,, | ,, | ,, | 3·55 ,, | 0·45 ,, |
| 08 | ,, | ,, | ,, | ,, | 3·60 ,, | 0·40 ,, |
| 07 | ,, | ,, | ,, | ,, | 3·65 ,, | 0·35 ,, |
| 06 | ,, | ,, | ,, | ,, | 3·70 ,, | 0·30 ,, |
| 05 | ,, | ,, | ,, | ,, | 3·75 ,, | 0·25 ,, |
| 04 | ,, | ,, | ,, | ,, | 3·80 ,, | 0·20 ,, |
| 03 | ,, | ,, | ,, | ,, | 3·85 ,, | 0·15 ,, |
| 02 | ,, | ,, | ,, | ,, | 3·90 ,, | 0·10 ,, |
| 01 | ,, | ,, | ,, | ,, | 3·95 ,, | 0·05 ,, |
| 1 | ,, | ,, | ,, | ,, | $4{\cdot}00\ SiO^2$ | |
| 2 | ,, | ,, | $0{\cdot}1\ Fe^2O^3$ | $0{\cdot}4\ Al^2O^3$ | ,, | |
| 3 | ,, | ,, | 0·05 ,, | 0·45 ,, | ,, | |
| 4 | ,, | ,, | $0{\cdot}5Al^2O^3$ — | $4SiO^2$ | | |
| 5 | ,, | ,, | 0·5 ,, | 5 ,, | | |
| 6 | ,, | ,, | 0·6 ,, | 6 ,, | | |
| 7 | ,, | ,, | 0.7 ,, | 7 ,, | | |
| 8 | ,, | ,, | 0·8 ,, | 8 ,, | | |
| 9 | ,, | ,, | 0·9 ,, | 9 ,, | | |
| 10 | ,, | ,, | 1·0 ,, | 10 ,, | | |
| 11 | ,, | ,, | 1·2 ,, | 12 ,, | | |
| 12 | ,, | ,, | 1·4 ,, | 14 ,, | | |
| 13 | ,, | ,, | 1·6 ,, | 16 ,, | | |
| 14 | ,, | ,, | 1·8 ,, | 18 ,, | | |
| 15 | ,, | ,, | 2·1 ,, | 21 ,, | | |
| 16 | ,, | ,, | 2·4 ,, | 24 ,, | | |
| 17 | ,, | ,, | 2·7 ,, | 27 ,, | | |
| 18 | ,, | ,, | 3·1 ,, | 31 ,, | | |
| 19 | ,, | ,, | 3·5 ,, | 35 ,, | | |
| 20 | ,, | ,, | 3·9 ,, | 39 ,, | | |
| 21 | ,, | ,, | 4·4 ,, | 44 ,, | | |
| 22 | ,, | ,, | 4·9 ,, | 49 ,, | | |
| 23 | ,, | ,, | 5·4 ,, | 54 ,, | | |
| 24 | ,, | ,, | 6·0 ,, | 60 ,, | | |
| 25 | ,, | ,, | 6·6 ,, | 66 ,, | | |
| 26 | ,, | ,, | 7·2 ,, | 72 ,, | | |
| 27 | ,, | ,, | 20·0 ,, | 200 ,, | | |
| 28 | $1Al^2O^3$ — | 10 $SiO^2$ | | | | |
| 29 | ,, | 8 ,, | | | | |
| 30 | ,, | 6 ,, | | | | |
| 31 | ,, | 5 ,, | | | | |
| 32 | ,, | 4 ,, | | | | |
| 33 | ,, | 3 ,, | | | | |
| 34 | ,, | 2·5 ,, | | | | |
| 35 | ,, | 2 ,, | Pure kaolin with traces of alkali. | | | |
| 36 | ,, | 2 ,, | Pure clay. | | | |

The temperatures at which these pyrometric tests fuse have been exaggerated by Seger; also, in default of precise results, it is better to leave out uncertain values. By way of a very general reckoning, these are the numbers of tests which are used in various potteries: —

| | |
|---|---|
| Muffle firing for decoration . . . . | 022 to 010 |
| Burning fusible bodies . . . . . | 015 ,, 01 |
| Burning slightly fusible bodies . . . | 1 ,, 10 |
| Stoneware burning . . . . . | 5 ,, 10 |
| Burning the body for fine faience . . | 3 ,, 10 |
| Burning the glaze for fine faience . . | 010 ,, 01 |
| Burning fireclay ware and porcelain . . | 10 ,, 20 |

The tests from 20 to 36 are only used in experiments for fusibility.

The mixtures composed as in the foregoing table are moulded into the form of prisms as shown in Fig. 186.

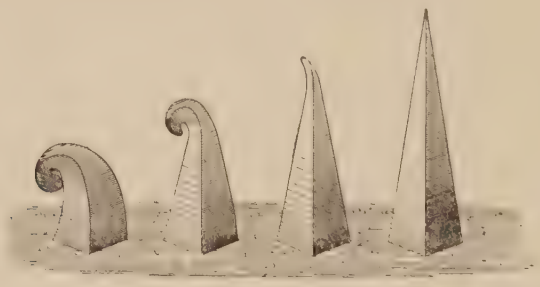

Fig. 186.—Pyrometric Tests.

This figure shows the manner in which, under the influence of heat, the prisms diminish in size, then bend over before melting. For a first experiment a series of tests must be procured, and placed in the kiln opposite a sight-hole; notice is taken, when the heat of burning that is suitable has been reached, of the number of the one which has begun to bend over, the following one being still whole. This having been determined once for all, it is sufficient to use the four or six nearest tests to regulate the highest temperature in the after burnings. Tests can also be prepared by following the compositions in the table, and afterwards comparing them with the normal tests by Seger.

*Pyrometers* are much less frequently used in pottery than tests are; we shall, therefore, simply mention the different types, only describing those which are sometimes used.

*Wedgwood's pyrometer*, based upon the shrinkage of the clay, is scarcely used because of its lack of exactness. The apparatus based on the *expansion of bodies* either solid, liquid or gaseous (metallic pyrometer, Gauntlett's pyrometer, Wiborgh's pyrometer, air pyrometer, thalipotasimeter, etc.) can only be used at temperatures below that for burning almost all pottery.

The *pyrometer by the circulation of water*, by M. de Saintignon, consists entirely of an iron tube put into the kiln, through which runs a current of water having sufficient velocity to prevent evaporation. The difference in temperature between the water when it goes in and when it comes out again, as measured by thermometers, is an evidence of the temperature of the kiln. This apparatus, when well regulated, may be of service, but the preparation of it is somewhat costly.

In the *actinometric pyrometer* by M. Latarche a mercurial thermometer is arranged in such a manner as to be affected outside the kiln by the radiation of one part of the interior. It is placed in a metallic tube surrounded by a reservoir of water, which is kept boiling by the heat of the kiln. A certain proportion between the temperature shown by the thermometer and that of the kiln is allowed. This apparatus, which is evidently more accurate than the eye of the observer, has, however, the drawback of being influenced by the nature of the atmosphere of the kiln.

Siemens's *electric pyrometer* is based upon the difference in resistance that is offered to an electric current by a platinum wire according to its temperature. This somewhat delicate apparatus, which is easily disarranged, is hardly suitable except for scientific researches.

In the *thermo-electric pyrometer* by M. Le Chatelier is measured the electric current, varying in strength, which is produced by heating a couple formed of a platinum wire and a wire of an alloy of platinum, with about $\frac{1}{10}$ of iridium or rhodium. The valuing of this current is done by an aperiodic galvanometer, the deviations of which are noted by means of a Poggendorf reflector.

In order that this apparatus may give good results, the couple must be placed at a fixed position in that part of the kiln the

temperature of which it is desirable to measure, care being taken that there is no entrance of air round the wires, the galvanometer, on the other hand, being put in an isolated position. When these conditions are properly complied with, this pyrometer is decidedly the one that gives the most accurate observations.

The *pyrometric telescope* by MM. Mesuré and Nouel is a portable apparatus, shown in Fig. 187, with which can be seen an object placed in the kiln. It is based on the phenomena of rotatory polarisation of light. The luminous ray entering by A, crosses two Nicol prisms, P and A, which are separated by a quartz disc, Q, before arriving at the observer's eye placed against the object glass, O. The colour seen varies according to

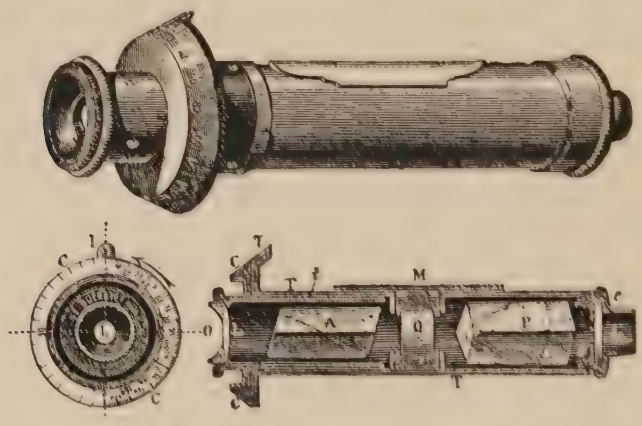


Fig. 187.—Pyrometric Telescope.

the intensity of the luminous source; by turning the eye-piece in the direction of the graduation of the circle C, a certain position of the prisms is found at which the colour passes rapidly from green to red, with an intermediate position at which there is a dirty citron shade. The measuring of the temperature is determined by the number of degrees that the eye-piece has been turned, starting with the zero of the apparatus, until the moment when this shade appears. This telescope may be put into the hands of the fireman, and may be of great use in regulating the upward working of the temperature, the tests, on the other hand, showing when the maximum heat has been reached.

Lastly, *the optical pyrometer* by M. Le Chatelier is based

on the comparison of the light given off by a definite part of the kiln with the flame of a trial lamp taken as a standard. Fig. 188 shows the arrangement of it in theory. The lamp, L, gives out luminous rays which are reflected by the mirror, M, and perceived by the eye, placed at the eye-piece, O. On the other hand, the rays coming from the kiln through the opening A are also perceived there, the two images being side by side, and thus easily compared. Their intensity is equalised by putting between more or less darkened glasses, B, and by diminishing the opening of a diaphragm, C. To make the observation easier, a red glass, D, is placed before the object in such a manner as to let only the monochromatic rays pass.

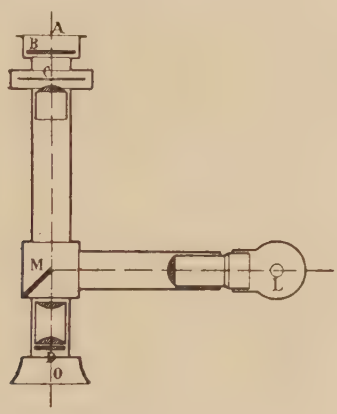


Fig. 188.—Optical Pyrometer.

The apparatus is graduated by aiming at a small palladium globe, soldered on to a thermo-electric couple.

These optical pyrometers have the advantage of not getting out of order, and of always giving observations that can be compared, yet the observer must be careful that the rays emitted by the object looked at in the interior of the kiln do not encounter on their way gases or flames, which would falsify the results.

**181. Cooling and Emptying.**—When the maximum temperature has been reached, and it has been kept up long enough to accomplish the soaking, the ware must be allowed to cool until it can be emptied. If the cooling may be done in an oxidising atmosphere, it can be hastened by continually

allowing a current of air to pass, which, according to the arrangement of the kiln, is either used for heating other ware, or else escapes by the chimney or through upper openings in the burning space.

If, on the contrary, the atmosphere is obliged to be kept reducing, all circulation is stopped, and the cooling is only accomplished by the radiation from the walls of the kiln. Yet, in this case, it is sufficient to continue thus up to the time when the composition of the atmosphere will no longer affect the colouring, that is to say, until the glazes have solidified or until the bodies have a temperature below dark red. After that time, the cooling may be hastened as in the preceding case.

In whatever way one works, the same precautions must be taken as in heating, so as to avoid a too sudden or uneven cooling, which would cause the ware to split. It is especially when they are nearly cold that it is advisable to be prudent and not be in too much haste to take them out.

Emptying is the last operation in baking. It is a very simple one, although often very difficult because of the heat; it is generally done by skilful management and does not need any special directions.

**182. Thermic Yield of the Kilns.**—The thermic yield of the kilns is determined by the relation between the heat really used to burn the ware and that given by the combustion. If $c$ be the number of caloric units really made use of, and C the number of caloric units produced in the kilns, the relation $\frac{c}{C}$ represents the yield of the kiln, and $\frac{C-c}{c}$ the proportion of heat lost.

Although this definition is very simple, that is not the case with the calculations and observations which have to be made to find the value of $c$ and C. In order to work methodically, it is best first to try and find the value of $c$, then to take account of all the loss of heat. By adding together all the amounts thus obtained, one ought to be able to find the number of caloric units C; this also being determined, on the other hand, by multiplying the weight of fuel used by its calorific power.

The *number of caloric units theoretically necessary to burn a definite weight of pottery* may be reckoned as follows: to the heat necessary for raising this weight of pottery to the maximum temperature T must be added that absorbed by the evaporation of hygrometric water, by the decomposition of the hydrosilicate of alumina and the breaking up of the carbonates. On the other hand, the formation of silicates is accompanied by an evolution of heat. As the heat evolved or absorbed by the formation or decomposition of the silicates has not yet been determined, we are forced to allow, in the absence of all exact data, that these two phenomena counteract one another.

The heat used to raise from 0° to T° 1 kilogramme of burnt ware is equal to 0·2T, allowing for the specific heat of pottery the amount of 0·2. As T varies from 800 to 1,375, the value of 0·2T is from 160 to 275 units of caloric.

On the other hand, if the quantity of water contained in the body is $a$ per cent., the heat necessary to evaporate it at 500° C. is

$$\frac{a}{100 - a}\,[606{\cdot}5 + (0{\cdot}305 \times 500)].$$

We have seen that $a$, at the maximum, might be equal to 13·9, which would correspond to an expenditure of 122·5 caloric units.

Lastly, the hygrometric water being reckoned equal to $b$ per cent. gives about

$$\frac{b}{100 - b} \times \frac{100}{100 - a}\,[606{\cdot}5 + (0{\cdot}305 \times 100)] \text{ caloric units.}$$

This gives, $b$ varying from 4 to 6 per cent., an expenditure of 26·5 to 47·1 caloric units.

It follows that 1 kilogramme of burnt ware needs, theoretically, a maximum of 445 caloric units for burning it, and that this amount may be as low as 245 caloric units for fusible bodies. If carbonate of lime enters into the composition, it would be necessary to add to these numbers $\frac{21{\cdot}7 \times n}{100}$ caloric units, $n$ being the proportion of carbonate in the body (Berthelot); but this amount, being always small, may comparatively not be taken into account in the preceding.

The causes of *loss of heat* may be divided into six parts, which will be successively dealt with:—

1. Loss due to charging, when this requires the use of saggers, supports, etc. To find the value of this loss we must determine the weight of the accessories thus used in charging 1 kilogramme of burnt ware. This number is afterwards multiplied by $0{\cdot}2 \times T$, the product giving the number of caloric units lost. In certain kinds of ware, the weight charged that is of use sometimes does not amount to a fifth part of the total weight of the charge. This remark shows the advantage, which is considerable from a thermic point of view, of charging things open, and the reason there is for not charging in saggers when it is possible to avoid doing so.

2. Loss due to the heating of the walls of the kiln. To find the value of this we may reckon that all the inside walls of the burning space have to be heated for a thickness of 15 to 25 centimetres, according to the temperature for burning, up to a degree of heat equal to that of the ware. As to the walls placed in the burning space, naturally they have to be raised entirely to the temperature of the burning. The valuing of this loss is found by multiplying, as before, the weight of the masonry heated by $0{\cdot}2 \times T$. From this point of view the most economical kilns are those which offer the greatest space to be utilised for the minimum of wall. This condition is best fulfilled by round kilns and kilns with continuous firing and one space for burning; on the contrary, in continuous kilns with several chambers this loss often becomes considerable enough to make up for the advantages that are gained by the continuity of the burning.

3. Loss due to the radiation from the outer wall of the burning space. This is the most difficult one to reckon and ought to be the subject of direct observation. In certain kinds of well built kilns, with thick walls, it may not reach 10 per cent.; in others it rises to 25 per cent. We need only remark that it increases with the exterior surface of the walls, and that it is produced particularly in the upper part of the kilns, especially by the domes of the burning space.

4. Loss occasioned by the warm gases passing out through the chimney, which can only be precisely reckoned by determining

at frequent intervals their volume and temperature. The latter can be measured fairly easily by thermometers or pyrometers. As to volume, that can be deduced from the velocity of the gases passing through an opening of a definite size, the velocity being reckoned by means of anemometers. These apparatus, however, work badly in gases filled with coal dust, and they do not work at all when the gases are rather hot. It is generally preferable to reckon the volume of gases from the weight of fuel burnt and from their chemical analysis. If we know the composition of the fuel, we can conclude the volume of air that is strictly necessary for its combustion, a volume which is afterwards increased or diminished in proportion to the amount of oxygen or of combustible gases indicated by the analysis of the gases of combustion.

We must remark, while on the subject of this loss, that when the gases are not given off at a temperature above 100° or 150° C, the heat thus evolved is indispensable for the working of the kiln; it is only when the temperature of them rises above this height that there is any real loss.

An oxidising state, by increasing the volume of the circulating gases, also increases the loss of heat. This, however, is much more important in intermittent kilns, while in continuous kilns, as we shall see further on (Art. 207), it is sometimes more economical to have a very oxidising working.

5. Loss resulting from a reducing working. This is fairly easily reckoned from the analysis of the gases, compared with the quantity of fuel burnt during the continuance of the reducing period.

6. Loss of heat which is caused in the fireholes, on account of imperfect combustion. It is determined by weighing the ashes, the cinders, and by reckoning the proportion of combustible material which they may still contain.

In the case of heating by gas, we can besides reckon the loss due to the generation of gas, which was discussed in Art. 159.

When the heat contained in the burnt ware can be partly utilised, as is the case in continuous kilns, this constitutes a *gain of heat* which will lower the foregoing losses.

By adding to the number of caloric units which are theoretic-

ally necessary for the burning those which result from the different causes of loss that have just been enumerated, and by subtracting, if there is any, the gain of heat, we ought, if it has been properly worked out, to be able to find the amount that represents the total heat evolved by combustion. It has already been stated that this can be arrived at, on the other hand, by multiplying the weight of fuel used by its calorific power. It is only when this balance has been established between the quantity of heat produced and that evolved that we can pretend to know precisely the working of a kiln. We shall find in the following chapters other remarks on this method of calculation, but we must not disguise the fact that the problem often is not easily solved, and requires men as experimenters who are familiar with the question of heating.

# CHAPTER VIII.

## DECORATION.

SUMMARY.—§ 1. *Colouring Materials:* General Remarks on the Colouring Materials —Colouring Metals—Preparation and Properties of the Colouring Materials.

§ 2. *Processes of Decoration:* General Remarks on the Processes of Decoration—Decorative Moulding of the Body—Colouring of the Body—Coloured Slips—Under Glaze Colouring—Coloured Glazes—Over Glaze Colouring—Decoration with Metals—Decoration with Metallic Lustres—Various Methods of Decoration—Burning the Colours.

### § 1. COLOURING MATERIALS.

**183. General Remarks on the Colouring Materials.**—Before discussing the different methods of decorating the ware, it is necessary to give some details on the colouring materials used in pottery. In this term are included only those that are fixed or developed by heat, that is to say, the coloured mineral matters that resist the lower or higher temperatures. They owe their colouring to oxidised combinations, and to the salts of one or more of the thirteen following metals: iron, copper, chromium, cobalt, manganese, nickel, uranium, titanium, antimony, gold, silver, platinum and iridium, to which may be added vanadium, molybdenum and tungsten, hitherto not used.

These colouring matters may be fixed either in or on the ware by five different methods:—

1. They can be introduced into the body, which then becomes a *coloured body*, which may either remain unglazed or be covered with a transparent glaze.

2. Coloured bodies can be used to cover another body with slip (Art. 114), in which case they are called *coloured slips*, the ware thus decorated either remaining unglazed or being covered with a transparent glaze.

3. The slipped body can be covered or not with a layer of

colouring matter, which is afterwards made adhesive by covering it with a transparent glaze. This method of decoration is known by the name of *under glaze colouring*.

4. The colouring matter can be mixed with the glaze, which thus becomes a *coloured glaze*, being either transparent or opaque.

5. Lastly, the colour can be put on the surface of the transparent or opaque glaze, in which case the colouring matter must be mixed with a flux, that is to say, made into *vitrifiable colour*. This method of decoration then consists in *over glaze colouring*.

Two or more of these methods of colouring can be used simultaneously to help in the decoration of the same piece of pottery.

When the colouring matter is incorporated with a body or a slip, it must be able to resist the same temperature as that at which the body is burnt; when it is placed under or mixed with the glaze, it must bear the temperature at which that glaze vitrifies; lastly, when it is put on the surface of the glaze, or even when this deposit is made on the raw glaze, then one returns to the preceding case, or if the glaze has been burnt first, then it need only bear the temperature for vitrifying its own flux, which is decidedly below that for burning the glaze.

In this last case the colouring matter is called *colours for muffle fire*, in all the other cases it is *colours for hard fire*. We see that these names do not mark definite temperatures, but that they depend on the temperature at which the ware is burnt. Such a colour for muffle firing, for example, placed on porcelain, may have to bear a heat higher than the colour for hard firing, which is used to decorate faience. Thus these names, as commonly used, have no value from the standpoint of pottery, and cannot in any way be used for classifying the colouring materials. A classification of this description is, besides, of very little use, and it is sufficient to call the colouring materials and colours by the names of the compound minerals to which they owe their colouring.

Now, if we consider this colouring by itself, we may notice that it is influenced—

1. By the temperature for burning.

2. By the atmosphere of the kilns being oxidising, neutral or reducing.

3. By certain materials in the bodies, glazes, or fluxe, which, however, are themselves colourless.

4. By the reciprocal action that the colouring matters may exert, the colouring of their mixture not being necessarily a means for their proper colour.

In this connection, we have already seen the variable colours produced by the oxide of iron in the body (Art. 147), and we have remarked that the glazes can be classified, as alkaline, boracic or plumbiferous, according to the influence they exert on the development of the colours.

Thus it is impossible in pottery to give such a narrow classification of colours as, for example, Chevreul has done for the dyeing industry. In a general way, the colours can not be made lighter or darker by simply adding white or black to them. It is advisable, on the contrary, to consider each of them separately, and to try and obtain the various tones that can be got in them by varying the proportion of colouring matter added to a definite quantity of body, glaze or flux, or in some cases by increasing or lessening the thickness of the coloured layer.

Having laid down these general principles, we will now discuss the colourings given by the thirteen usual colouring metals.

**184. Colouring Metals.**—*Iron.*—We have seen, in the preceding chapter, the different colours that oxide of iron can give to the bodies; it now remains to examine its action in glazes. For relatively low temperatures, generally below 1,000° C., and in an atmosphere which is slightly oxidising, iron oxide gives the colouring of the peroxide, that is to say, brown and red, which may become violet and approach black in consequence of the presence of the monoxide. It is then suspended in the vitreous mass, with which it does not easily mix. For higher temperatures it may enter into combination, and then gives colours that are slightly stable, of a bluish green in alkaline glazes, of a brownish yellow in boracic glazes, and of a more or less clear yellow in plumbiferous glazes. Finally, at very high temperatures it forms silicates of the protoxide, which are scarcely coloured if it is only

in a small proportion, and of a reddish or blackish brown if there is much of it.

On the other hand, mixed with other colouring oxides, it may give very stable colourings, that are much used.

It is obtained in a pure state by calcining the sulphate of iron; it is then in the form of a red powder or colcothar, of which the shade depends on the rapidity with which it is calcined and at what temperature. It can also be prepared by precipitating the salts of iron by ammonia or by alkalies. The tint it takes, in this case, depends upon the salt employed and also on the reagent.

Lastly, it is found in Nature in many earthy compounds, such as ochres, Sienna earth, Thiviers stone, Armenian earth, etc., but these usually have the disadvantage of being very variable in composition.

*Copper.*—The oxides of copper are only used in the glazes that can be vitrified at a moderate temperature. At high temperatures they have a tendency to absorb into the glaze and even to penetrate into the body itself. With an oxidising atmosphere, that is to say, in the form of dioxide, copper in alkaline glazes gives a beautiful azure blue colour, known by the name of turquoise blue. It becomes a more or less intense green in boracic or plumbiferous glazes. With a strongly reducing atmosphere it forms the monoxide and makes a beautiful purple red in alkaline glazes, verging more on orange or brown in the others.

Mixed with other colouring matter, the oxide of copper mostly has the effect of making greens.

It is especially used in the form of the anhydrous dioxide, which is a very dense black powder, obtained by calcining nitrate of copper. The carbonates are also used sometimes. As to the blue ashes and other ores which are somewhat impure, they cannot be recommended.

*Chromium.*—The oxides of chromium can only be used for colouring very white bodies, because the small quantity of iron which is contained in them always darkens and dirties the colours. In glazes chromium is used in the form of the oxide of chromium or of chromic oxide. The atmosphere of the kilns exercises a certain amount of influence on them, the chromium

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taking the form of chromic acid when the atmosphere is oxidising, and that of the oxide when the atmosphere is a reducing one. However, this action is much less marked than with iron or copper. With a sufficient proportion of the colouring matter, it is only felt by slightly modifying the shades. The oxide of chromium in alkaline glazes gives a bluish green or a greenish blue, which is very little used; on the other hand, in other glazes it produces a beautiful green colour which becomes yellowish by a small proportion of the oxide with an oxidising atmosphere. Chromic acid produces rather intense yellows in alkaline or purely plumbiferous glazes, and yellowish greens in boracic glazes. In alkaline plumbiferous glazes at a low temperature it gives an orange red colour. Lastly, by mixing stannic acid in the glaze with lime and a small proportion of chromic acid, a red colour is obtained varying from rose to purple, when the temperature is sufficiently high. This colour is not specially due to the chromic acid, because it can be obtained under the same conditions with other substances, but the use of chromium gives the best results.

The compounds of chromium are also very much used as mixtures with other oxides to produce greens with copper, blacks with the oxide of iron, etc.

The oxide of chromium is prepared by decomposing the chromate of mercury by heat, or by acting on the chromate of potassium when heated with sulphur. As to chromic acid, it is used in the form of bichromate of potash. The use of chromium in pottery only dates from the beginning of this century; thus the presence of it in the ware may sometimes furnish indications as to the date of their manufacture.

*Cobalt.*—The oxide of cobalt is a very powerful colour; it may be used for colouring the body and resists all temperatures. The colour it gives is always blue. Added alone to a glaze, it gives an intense blue colour, inclining slightly to violet, but it cannot easily be obtained pure in the light shades. It works better mixed with the oxide of zinc, giving ultramarine blue; added to aluminium, it produces a beautiful sky-blue colour.

It is mixed with the other colouring oxides to obtain all shades of blue.

The oxide of cobalt in a small number of colour factories is obtained by the treatment of the ores of cobalt. It is sold in the state of protoxide of cobalt almost pure, which is a dark grey powder; but for the more usual glazes, or for colouring fine bodies, the sesquioxide is used, which contains 85 per cent. to 90 per cent. of oxide. Finally, for the ordinary bodies, it is more economical to use the rose grey carbonate of cobalt, or the silicate of cobalt called rose cobalt, which only contain 40 per cent. to 50 per cent. of the oxide. All these are always more or less mixed with the oxide of nickel.

*Manganese.* — The oxide of manganese is also rather a powerful colour, which allows of its being used for bodies to which, when almost always mixed with iron, it gives a dark brown or black colour, resisting any temperature. In glazes it forms colours varying from brown to violet, according to the amount of iron oxide, and according to the composition of the glaze. In alkaline glazes it is more particularly violet, and brown in the boracic ones; plumbiferous glazes are midway between.

Mixed with iron oxide, the oxide of manganese makes browns, and it may enter into the composition of almost all blacks.

It can be extracted almost pure from the ores of manganese; then it is in the form of a black powder, which is preferable for using in glazes, especially for violet ones. In other cases the ores themselves are used, having been simply sorted, washed and powdered.

*Nickel.*—The oxide of nickel is scarcely ever used, because it gives uncertain and spotted shades, varying from yellowish green in alkaline glazes to dirty green in boracic ones, and brown green in plumbiferous ones. It is used as a mixture specially with iron, and then gives a shining brown; it also enters into the composition of certain blacks. It is extracted, in the form of a green or grey oxide, from the nickel ores.

*Uranium.*—Oxide of uranium gives yellow colour with an oxidising firing, and green or black in a reducing atmosphere. As the price of it is rather high, it is scarcely used except in plumbiferous glazes, in which it gives, with a moderately

oxidising working, a very bright orange yellow. It is extracted from an ore known by the name of pitch-blende, which can also be sometimes used direct.

*Titanium.*—We have seen the colours that titanic acid can give to the body (Art. 147). In glazes it only gives yellow tints, due, partly at least, to the iron that raw titanic acid always contains in commerce.

*Antimony.*—Oxide of antimony forms with lead a compound of a yellow colour. In all other cases it does not give any colour itself, but acts on others by making them opaque. It is usually employed mixed with oxide of iron, with which it forms a beautiful series of yellows. It is sold in the form of antimonic acid, and as an antimoniate of potash; these are obtained by treating metallic antimony. It may also be obtained in the form of antimoniate of lead, known by the name of Naples yellow.

*Gold.*—Gold that is prepared under special conditions, which will be discussed further on, may be used for decorating pottery either as dull gold, which can be made brilliant by burnishing, or else directly as brilliant gold. If it is introduced into glazes as a chloride, it gives them a colouring that varies from rose to purple, which resists high temperatures, but has the disadvantage of being dear. By mixing a chloride of gold with a chloride of tin, a precipitate of a violet purple is obtained, known by the name of Cassius purple, which, in glazes, gives beautiful rose, purple, carmine or violet colourings, but which, when the temperature is raised above 1,000° or 1,100° C., take a bluish-violet tinge and then disappear.

*Silver.*—This metal also is added to glazes as a chloride, giving them a yellow colour which is seldom used. In the same way it is seldom used for silvering, because of the low temperature at which it fuses; but it is often added to Cassius purple.

*Platinum.*—As we shall see further on, platinum may be used to cover the ware with a layer of dull platinum, made brilliant by burnishing. Added to glazes as a chloride, it gives a grey colour, which resists high temperatures, but is somewhat costly.

*Iridium.*—This metal can be introduced into the glazes as an oxide, and then gives a colour varying from grey to black. It is very little used on account of its high price.

**185. Preparation of the Colouring Materials.**—The manufacture of the simple colouring materials is now done in special works. Each of these materials requires, in fact, special methods of manufacture, necessitating sometimes long preparations, if it is desirable to obtain them sufficiently pure. Besides, we must remark that the manufacture of them needs special knowledge, and that it is considerably more economical when it is possible to deal with a larger quantity of the raw materials than is used even in the largest pottery. It is, therefore, useless, for the object that was proposed for this work, to enter on this subject into more detailed explanations; also, in what follows we shall discuss only the mixtures of the simple colouring materials, and the manufacture of certain compound colouring substances, which are often prepared in potteries. We shall follow a classification based on the colours, dividing them into whites, blacks, greys, blues, greens, yellows, reds, browns and violets.

*Whites.*—All the bodies which contain none or only very little iron oxide are white, and may be used as white slip. As to glazes, they can only be made white by doing away with their transparency. All the materials which cause opaqueness—oxide of zinc, calcium, arsenious acid, alumina, etc.—which have already been discussed (Art. 132), are white; the choice then is only embarrassing.

*Blacks.*—Blacks can be obtained in different ways:—

1. By using oxide of iridium alone, or oxide of uranium also alone, but only in a reducing atmosphere.

2. By a mixture of two oxides, one of which must always be oxide of iron or of manganese, and the other the oxide of cobalt, chromium or uranium. Among these mixtures, the ones most used are those of iron and chromium, iron and cobalt, manganese and uranium.

3. By the mixture of three or four oxides, composed always of iron and manganese, to which are added cobalt, chromium and copper.

In all these mixtures, different shades are obtained by making one of the colouring materials predominate. Thus, iron gives brown tints, cobalt blue tints, manganese violet tints, and chromium green tints. These colouring materials are used directly in the form of oxides; yet sometimes the chromate of the protoxide of iron is also used; this is obtained by precipitating a solution of neutral chromate of potash by a salt of the iron monoxide, also in solution.

*Greys.*—By lessening the proportion of black colouring materials, naturally we can obtain grey, yet the mixture of iron and cobalt is principally used. We must remark that grey is more difficult to get than black, because the mixture of colouring matter must be very precisely adjusted not to give the grey yellowish, greenish or bluish tints, which are very ugly. Platinum gives a beautiful grey, which has only the disadvantage of being costly. For this purpose, platinum, after having been dissolved in *aqua regia*, is precipitated by ammonia, and the liquid evaporated and then calcined. Thus an extremely fine powder of platinum is obtained.

*Blues.*—All the blue colourings are given by cobalt. This is sold in the forms of oxide, carbonate, silicate or phosphate of cobalt. Unmixed, it gives a beautiful blue, which is slightly violet; as we have seen, by mixing it with oxide of zinc or with alumina ultramarine or sky-blue colours are obtained. The greenish-blue shades are obtained by mixing a little oxide of chromium; in the same way, the blue becomes more violet by the addition of a small quantity of oxide of manganese. The burning of the colours from cobalt must be done in an oxidising atmosphere, or at least a neutral one.

We have seen that the oxide of copper with an alkaline glaze, and burnt with a decidedly oxidising firing, gives a beautiful colour, known by the name of turquoise blue. We must remark that the copper monoxide is black, and the dioxide red; it is only the silicate of the monoxide that is blue.

*Greens.*—The green colours are produced by means of chromium in the form of oxide of chromium. In alkaline glazes the tint of a bluish green is changed to green by a mixture of copper oxide. The bluish greens are obtained in all glazes by a

mixture of chromium and cobalt. The addition of a little iron makes them approach yellow and brown. A mixture of chromium and nickel also gives a green which is sometimes used. Similar to the greens furnished by copper alone, in boracic and alkaline glazes, it is very little used.

*Yellows.*—The yellow colours are numerous; these are the principal:—

1. Pure iron oxide, specially used in the body; at a high temperature turns brown.

2. A mixture of oxide of antimony and oxide of lead, to which is often added a little iron oxide.

3. Pure oxide of uranium, the tint of which becomes orange when lead is present.

4. Oxide of titanium mixed with oxide of zinc.

5. Chromic acid, but only in alkaline glazes.

At high temperatures only uranium and titanium can be made use of.

*Reds.*—Rose, reds or purples are obtained by iron, chromium, copper or gold, according to circumstances.

1. The red colour due to iron can only be obtained at a temperature below 1,000° C.; above that it becomes brown, then blackish. In glazes its shade depends entirely on the way in which the iron oxide has been prepared.

2. A mixture of oxide of zinc, carbonate of lime and a small proportion of chromic acid gives a red colour called carnation red or pink, but only with an oxidising atmosphere. First, the mixture of the oxide and carbonate is finely powdered, a solution of bichromate of potash is added to it, then the mass is dried, calcined, powdered, washed and dried again. A certain quantity of quartz added to the mixture gives shades which are more decidedly red.

3. By mixing chloride of gold with a white clayey body, added to which is carbonate of soda, the mixture taking place as a liquid paste, then being dried, a mass is obtained which has a beautiful purple colour, that resists high temperatures, but which naturally is very dear.

4. For low temperatures it is replaced by Cassius purple. This is obtained in the following manner: On one side a solution

of gold is made in *aqua regia*, which afterwards is evaporated to take away the excess of acid; then it is dissolved in water. On the other hand, tin is dissolved in concentrated hydrochloric acid, then evaporated, and the salt allowed to crystallise. This is dissolved in water and half the solution is treated with a current of chlorine, which changes the chloride of tin into a dichloride. The two solutions of chloride and dichloride are put together, much diluted with water, the solution of chloride of gold is poured into it drop by drop. It makes a precipitate the colour of wine dregs, which is washed and dried. The method that has just been described can be varied in several ways, which are looked upon as secrets of manufacture by colour merchants.

Sometimes chloride of silver is added to chloride of gold to make the Cassius purple redder, as it has a tendency to turn to violet.

5. We have seen that oxide of copper also gives a beautiful red colour, but only with a decidedly reducing atmosphere; the employment of it, therefore, is limited to certain decorative effects.

*Browns.*—Browns are made by oxide of iron, either alone at high temperatures or mixed with the oxides of manganese, chromium, cobalt or nickel, which give them the most various shades.

*Violets.*—The violet tints are only made in a direct way by manganese in alkaline glazes. In other cases we must have recourse to a mixture of cobalt with one of the red colouring materials already described, specially with pink. Lastly, Cassius purple, with a flux that is rather more alkaline than plumbiferous, and when chloride of silver is not present, gives violet colour.

All the colouring materials ought to be very finely powdered and well mixed, in order to give a uniform colour and one that is regularly spread over. This powdering is done either by means of mortars for very small quantities, or by using the processes employed for powdering the glazes (Art. 141).

186. **Properties of the Colouring Materials.**—There are still a few remarks to be made on the combinations of the colouring materials, either with one another or with the other elements

in the bodies, glazes and fluxes, as well as about the effect they have on the fusibility and expansion.

At relatively low temperatures, the colouring materials may combine together to form salts, the colour of which is not intermediate between the colours of the component substances. Thus we have seen that oxide of antimony and oxide of lead, both of them white, form an antimoniate of lead that is a yellow colour. In these combinations, in a general way, the oxides that have the symbol MO (M being any kind of metal) act as a base, those with the formula $MO^2$, $MO^3$, or $M^2O^5$ are acids, while those having the symbol $M^2O^3$ or sometimes MO act, according to circumstances, as acids or bases.

Thus the monoxides of iron, manganese and cobalt, and the dioxide of copper are basic, while the compounds of antimony and chromium are acids. Among the salts which can be formed thus may be mentioned: chromate and antimoniate of iron, the manganates of cobalt and chromium, the ferrates of manganese, chromium, cobalt, etc.

By adding to the colouring matter properly so called other colourless metallic oxides, coloured salts can also be obtained, which have special shades. These colourless oxides, which have been mentioned among the raw materials for the glazes, are the oxides of tin, zinc and lead. The first, which is always acid, gives stannates, the second usually produces zincates, and as to the third, in the form of monoxide it makes bases, and plumbates when it is in the form of red lead. We may mention as examples the stannate of chromium, the zincate of iron, antimoniate and chromate of lead, etc.

Among the alkaline earthy bases, which may also be found mixed in colours, lime, baryta and magnesia constantly act as bases, while alumina more often plays the part of an acid. Example: chromate of baryta and aluminate of cobalt.

Lastly, the alkalies (soda and potash) naturally are always basic, while boracic acid and silica are always acid.

The number of combinations that can thus be formed explains the numerous variations in the shades of pottery colours, as well as the impossibility of mixing, in a general way, several colours in order to obtain a middle colour.

When the colouring matter has to be fixed to the surface of the glaze, fluxes are added to it, that is to say, materials which, with the colouring matter, form vitreous compounds. Then it is easy to give the vitrifiable colour the desired composition to obtain the colour wished for; this, added to the low temperature needed for baking them, explains why the series of vitrifiable colours sold by colour manufacturers is so rich, and comprises all the shades imaginable.

The same is not true when the colouring materials or their compounds are mixed in the body or glazes, the composition of these not being dictated solely by considerations of colour. The result of this first circumstance is that the number of colours is noticeably diminished, but there is a second reduction which is more important, in the fact of the higher temperature needed for burning the body or vitrifying the glaze. Under the influence of heat the chemical affinities of the different substances present are modified. Particularly, the acid properties of silica develop at the rate that the temperature increases, so that silicates are progressively substituted for antimoniates, ferrates, zincates, stannates, manganates, plumbates, aluminates, and at the temperature for burning porcelain the silica remains the only acid element, together with boracic acid.

We see that it is advisable to try and retard as much as possible the action of silica, by forming, between the colouring matter and the other elements of the body or the glaze, compounds that resist it as much as possible. It may be admitted with Seger that the most stable combinations, from this point of view, are those that have the composition of spinelles, that is to say, which are formed by the combination of a protoxide and a sesquioxide.

The preceding only applies, let it be understood, to the colouring materials that are capable of combining with the elements of the fluxes, the glaze or the body. Certain of them act, either by making them opaque by not entering into combination at the temperature at which they are burnt, as in the case of several colours for over-glaze painting, or else by remaining unattacked at high temperatures, such as gold and platinum.

The introduction of the colouring matter into the bodies or glazes generally has the effect of increasing the fusibility. Among the most usual colouring oxides, that of chromium seems the least fusible, then those of iron, manganese and uranium, and, lastly, those of cobalt and copper. It is advisable to take these facts into account, to modify, if possible, the composition of the body or glaze, so as to render them more refractory.

As to what relates to expansion, it is known that all the colouring oxides make compounds with an expansion below that of oxide of lead (Art. 150); oxide of copper is the only exception. It is this property that makes it so difficult to obtain certain colours from copper, especially turquoise blue.

## § 2. Processes of Decoration.

**187. General Remarks on the Processes of Decoration.**—No object in industries or arts lends itself to so many different processes of decoration as pottery does. The body, on account of its plasticity, may take all kinds of form or decoration; the glaze itself may be a subject for ornamentation, and we have just seen that there are five methods of introducing colours into it. By employing either separately or simultaneously several of these decorative processes, most different results can be obtained, thus causing the art of sculpture to be allied to that of painting. There exists, besides, a series of processes of special methods, which multiply the decorative effects and allow them to be infinitely varied. A description of all the decorative processes that have been used would be entirely out of the scope of this work, and we will be content with summing up those which are, so to speak, classical, only mentioning the others and usually passing over in silence the decoration obtained by the simultaneous use of several methods of ornamentation. It must also be well understood that the question of art will not be dealt with, and that we shall confine ourselves to giving some practical advice as to the best way of using the various methods of decoration.

After having said some words about the decorative moulding of the body, we will describe the five processes for decorating with colour, then we shall speak of ornamenting by means of

metals, and, lastly, will be briefly mentioned some of the other methods which are the most used or the most fashionable. This chapter will be closed with some observations on the burning of colours, the last operation in the manufacture of the most complicated pottery goods.

**188. Decorative Moulding of the Body.**—In Chapter IV. was discussed only the common fashioning of the shape, that is to say, that of which the object was the producing of a larger or smaller number of similar objects, and without taking account of certain details of manufacture of a purely decorative kind. It remains now to complete what has been said already, but from a decorative point of view.

With this idea, the moulding may have two objects:—

1. The creation of a unique decorative object.

2. The decoration of objects that have been manufactured by one of the processes of industrial moulding.

The moulding of an original decorative piece of pottery naturally can only be done by modelling by hand, or, when the object is round, by forming it on a potter's wheel, often finishing it off by turning. It is impossible to give precise directions on this subject, the processes employed depending entirely on the nature of the body and on the form of the piece. However, the following are some general observations about it:—

Modelling and forming by hand need somewhat plastic clays; this is always the case for terra cottas and stoneware. The same usually applies to those used in the manufacture of faience; on the contrary, the bodies for porcelain are much more sandy, and present special difficulties. Agglutinants are often obliged to be added to them; size, dextrine, etc.

For the parts that are in high relief it is often more convenient and sometimes it is even necessary to mould them separately, and to join or stick them afterwards to the principal object. The ease with which this is done makes possible the modelling of very undercut objects and those with thin and delicate raised pieces.

The amount of damp in the body is of great importance. During the whole of the modelling the body must not be allowed to dry, being kept surrounded with damp cloths or

damped with sponges, but this inconvenience is done away with in a great measure by the ease with which the body can be carved when, after the modelling is finished, it has been allowed to harden. The body then lends itself to exact working in which the joints can be lost, the thicknesses be lessened, and the contour be made exact. In sandy bodies this carving replaces modelling to a great extent, as the piece can only be formed more or less roughly in that case. Thus it is also possible to join on the very thin parts in high relief, which would get out of shape if they were put on when they were still plastic.

It is very important to notice that it is impossible conveniently to dry and bake objects that have thick massive parts with other parts that are much thinner. If this should happen, it is absolutely necessary to hollow out the more bulky parts inside. When it is impossible to do this on a surface that is unseen, after the modelling is done, the body having become slightly firm again, the part to be hollowed out must be taken off in two or more pieces by means of metal wire, or with a thin blade. Each part is then hollowed out separately, the whole is stuck together again, and the joints are scraped off. Lastly, one must reckon for the shrinkage that all bodies have when drying (about one-tenth in plastic bodies), and the dimensions of the object must be increased at that rate in modelling.

What has just been said applies just as much to the decoration of the body, the moulding of which has been done by machine. It is often much easier to mould certain ornaments separately, or certain parts that are much raised, and to join them or stick them on afterwards. This method of moulding is especially suitable for little figures in high relief, for wreaths and for medallions that are used for decorating the ware.

The decoration by hollowed out designs that are frequently repeated may be done with stamps having the design cut in relief that it is desirable to print on the ware. They are pressed against the body when it is slightly firm, while it is held on the inside, if that is possible, to prevent it from getting out of shape with the pressure. When this hollowed out decoration forms a band in which the same motive is constantly repeated,

the stamp is replaced by a roulette wheel. These two processes in decoration are called *stamping* and *beading*. *Engine turning** can also be used, the same as is done in other industries, and does not present any difficulty. Lastly, plaques of rather large size can be ornamented by a design repeated indefinitely, by passing them under an engraved cylinder, with the hollows that are desired raised in relief.

When the body is nearly dry the surface can be polished by means of a horn; with this a shiny look can be given, at the same time as its hardness can be increased. Naturally, this is not done to unglazed ware.

In certain cases the glaze may finish the moulding of the body. Thus, with small pieces of clay, it is possible to make plaited objects, which would easily break if they were dipped into a glaze, as this would fasten the small pieces together. Also small hollows can be made in the body, which would afterwards be filled with glaze, and these, when the glaze is transparent, form a style of decoration which is quite of a special kind.

**189. Colouring of the Body.**—We have seen, in the chapter relating to firing, the different colours that the oxide of iron contained in the clay can give to the body. By mixing other colouring materials with it, coloured bodies of different shades can be obtained.

The colouring matter ought to be added in the form of an extremely fine powder, and be very carefully mixed with the body, if it is desirable to have a uniform colouring. Sometimes, so as to economise the colour, the surface only of the body is impregnated with it, when the body itself is very dry, or, better still, when slightly warmed. However, this process of *impregnation* very seldom gives uniform colours.

We must remark, in order that the colours may be stable, and not be removed by washing for example, that it is necessary the temperature at which they are burnt should be high enough to ensure their combining with the elements of the body. If that is not the case, and if it is advisable to entirely prevent this combination, so as, for example, to prevent the action that alumina appears to exert on them, they are fritted beforehand

* Or "Dicing".

in such a way as not to add them except in the form of stable compounds, and nearly always in the form of silicates.

Now we will give some details as to the different colours that can be obtained:—

*Whites.*—This colour is naturally that of the bodies which do not contain oxide of iron. We have seen that it is almost impossible to prevent the presence of it entirely, and that, notwithstanding a small proportion, white bodies can be got with a moderate heat for burning, but that, with vitrifiable bodies, a reducing atmosphere for burning must be used to obtain a slightly bluish white.

*Blacks.*—Black is nearly always got by a mixture of oxide of iron and oxide of manganese. According as one or the other preponderates, the black approaches brown or violet. In ferruginous bodies it is sufficient to add manganese to them.

For fine wares oxide of iron is sometimes used, to which a small quantity of oxide of cobalt has been added. The mixture mentioned before, of the oxides of iron, manganese, cobalt and chromium, can also be used.

It is also here necessary to call attention to that process of firing which consists with a very reducing working in reducing the oxide of iron, and depositing in the pores of the terra cotta particles of carbon, which result from the decomposition of the hydrocarbons that are given off from the gases of the furnace.

*Greys.*—Greys are naturally obtained with a smaller proportion of the oxides of iron and manganese. Yet, in order to have very light shades, it is necessary for the body first to be not at all, or only very slightly, ferruginous.

The most beautiful shades are obtained by the mixture of oxide of iron and of cobalt; the small quantity of the latter oxide that it is necessary to use makes this solution fairly economical. For fine vitrifiable bodies, the sesquioxide of iridium and chloride of platinum can also be used, either separately or mixed together.

*Blues.*—Blue colours can only be produced with white bodies, to which is added oxide of cobalt. The shades thus obtained depend not only on the proportion of the colouring oxide, but also on the quantity of alumina that the body contains. If it

is aluminous, the colour is sky-blue; if it is silicious, the shade approaches indigo. This latter colour (Persian blue), however, can be got in silicious bodies by first fritting the oxide of cobalt with its own weight of oxide of zinc. In the same way, the silicious bodies can be coloured sky-blue by first fritting oxide of cobalt with alum.

*Greens.*—Greens are obtained by mixing oxide of chromium with a white body. It is essential that the latter should be as free from iron as possible, otherwise the tints will be pale. The various shades are obtained by varying the amount of the colouring oxide, and by adding a little cobalt for bluish greens. Sometimes also oxide of nickel is used, which by itself gives a bright green, though it is a trifle uncertain, and which, mixed with a little oxide of cobalt, produces an olive green.

*Yellows.*—Yellow colours, orange yellow and yellow brown are produced in terra cottas by oxide of iron, by using the natural clays either alone or mixing them together for the shade desired. In vitrified bodies we have seen that with oxide of iron only a yellow body can be obtained when the atmosphere is an oxidising one; if the amount of the oxide is increased, then a blackish-brown colour is produced and not a deep yellow. In order to obtain the latter colour oxide of uranium must be used; this gives a beautiful yellow, but only when the atmosphere is decidedly oxidising. If it is a reducing one, the colour changes to a greenish grey.

*Reds.*—In terra cottas the red colours are also obtained with oxide of iron, but, as we have remarked in the preceding chapter, that they do not resist a high temperature. In a general way, intense yellow and red colours are very difficult, if not quite impossible, to get in vitrified bodies. When they are very white, they can, however, be coloured rose by chrome red. In that case bichromate of potash must be fritted with pure alumina, and this frit when finely powdered is added to the body. The addition of a small proportion of oxide of cobalt makes this rose colour turn to lilac.

*Browns.*—We know that this colour is given by iron oxide at a somewhat high temperature. For ferruginous bodies that

only need a moderate heat, it is easily produced by the addition of a little oxide of manganese. In finer white bodies a mixture of the oxides of iron and chromium is used, or iron chromate such as is found in certain minerals. A mixture of the oxides of manganese and chromium can likewise be used, or a frit of the oxides of zinc and chromium, obtained by heating sulphate of zinc with oxide of chromium.

*Violets.*—These colours can only with difficulty be obtained with oxide of manganese, or with chromium and cobalt.

**190. Coloured Slips.**—We have seen in the chapter relating to slipping (Art. 114), that, under the name of slip, is meant a body put on the surface of another body that has been already moulded. As has just been said, coloured bodies can naturally be used as coloured slips to decorate objects made out of other bodies. This decorative process is made use of, either from economy, by giving to the surface only a colouring, or some quality that it would be too costly to use for the whole body, or else for decorating the surface of the body with paintings or with reliefs in different shades.

In the first case the slip ought to be spread over the whole surface, or else only on the inside or outside of the piece, the ware being made of dry body or of a body warmed through by a first baking. The methods employed for putting on the coloured slip are the same as those mentioned, in Chapter IV., for colourless slips; there is, therefore, no need to repeat them.

In the second case the slip is usually put on with a brush, either on the raw paste, or on one that has been warmed through first, by employing the methods used for oil or water-colour painting. This method of decoration has been called "barbotine". The decorated ware, after having been dried, may be baked, if it is to be left rough, or else it can be coated over first with a colourless glaze which naturally must be transparent, and then burnt afterwards. The background, or the painted parts only, can also be coated with glaze.

In "barbotine" it is wiser only to use a small number of clear colours, without trying to give too much modelling to the design, and without trying to imitate oil painting in this method. A dull or slightly monotonous look is avoided in this

style of decoration by making the background more showy than the painted parts, or *vice versâ*.

By making the liquid paste of the slip slightly stiffer it is possible to make relief decoration with a brush, thus forming a kind of modelling, which can afterwards have the edges and the higher parts touched up by carving them with small hand tools.

The pasty slip may also be put into a pot with a very narrow spout, and be allowed to fall out drop by drop on to the ware, in such a way as to form round bulbs in relief, or lines or rosettes. This method of decoration is known as "pastillage".

By using a pot with several compartments filled with slips of different colours, and a number of spouts side by side, a many-coloured slip can just as well be allowed to trickle on to the ware, and thus *marbled effects* can be made. By covering the whole over with a glaze, imitations of different coloured marbles can be made.

In certain cases, especially for paving tiles, sometimes during the moulding are arranged, on the surface of the piece, cells that can be filled with slips of different shades, the surface afterwards being levelled by means of a knife.

Lastly, slip can be used for decorative purposes by incrustation, formerly described (Art. 114). In that case little moulds are used, divided by partitions of thin tinplate which form the outlines of the design that is desired, and these are filled with dried paste of various colours. After the separating partitions have been removed, the coloured slip is covered over with ordinary slip, which is also powdered, and the whole joined together by means of great pressure. A fuller description of these last two processes will be found in the articles devoted to the manufacture of tiles (Art. 250 and 274).

**191. Under Glaze Colouring.**—This process of decoration consists of colouring the raw or burnt bodies, either with or without being covered with slip, with colouring matter, and covering the whole with a colourless, transparent glaze, which develops and fixes the colours. We must not confound it with under glaze barbotine painting. In the latter the colouring matter is fixed in the slip, while in under glaze painting it is

the glaze into which the colours penetrate under the influence of heat.

When the whole piece has to receive a uniform colour, the method of putting it on described in Chapter IV. (Art. 114) is used, the colouring matter, powdered very finely, having been mixed with a sufficient quantity of water, to which a little gum arabic, treacle, glycerine, etc., has been added, so as to make it more adhesive. When the body has been heated through first, it is often best to make it less absorbent by soaking it in water or in a gummy or albuminous liquid. In that case it is necessary to heat the piece sufficiently to make the body absorbent again before the glaze is put on it.

Immersion can also be used to produce marble effects. The colours ground up with water or spirits are, in that case, put in a bath of gum tragacanth dissolved in water, on which, after they have been slightly stirred, they come to the top. Then the warmed piece is dipped into the bath, and absorbs the colour.

If, on the contrary, it is desirable to cover the piece with a pattern, the colours may be put on with a brush, or by printing.

For *under glaze painting with a brush*, the colours, ground to an impalpable powder, are, either with a muller or with a palette knife, diluted with gum arabic or spirits of turpentine on polished glass, and they are applied with a brush as in oil painting. The shading is obtained by tints put over one another. The ware thus decorated is afterwards dried, then coated with glaze according to the methods already mentioned.

*Decoration by printing* is done in an entirely different way. For this are used copper plates, beaten out with a hammer; on these plates is engraved the design that is required to be reproduced. This engraving ought to be done by stippling, using the graver as little as possible. On the other hand, a mixture of the colouring materials, powdered very finely, is made very carefully with printing oil. This latter is made by heating linseed oil, with the addition of a little resin or gum. The mixing is done with a muller on an iron plate heated to 150° C. or in a special apparatus for mixing printing colours.

This mixture is then taken up on a spatula and spread over the engraved plate, care being taken to make it go into the hollows by means of a dabber; then the excess of colour is taken off and the plate cleaned. The plate being thus prepared, it is covered over with a sheet of thin hemp paper, previously soaked in a watery solution of soft soap, and passed under a press to print. Then, after having put it on a hot plate, which is generally heated by steam, the paper is detached, and on it the colour remains; the part containing the design is cut off and applied to the pottery to be decorated, by rubbing it down with a roller. At the end of several hours the piece is steeped in water and the paper detached with a sponge. The impression remains sticking to the ware, which is afterwards dried, heated to 150° C. or 200° C. to evaporate the oils, then covered over with glaze and burnt.

We see that, by this process, only monochrome designs can be printed. Therefore, the decoration is often completed by painting with a brush, or rather by colouring.

In some cases the preceding process of printing can be replaced by a chromo-lithographic printing. But this method of decoration will be described further *à propos* of over glaze colouring.

In under glaze colouring the colours must resist the temperature for burning the glazes in which they are vitrified. The colouring matter used has been described in the last chapter. It is sufficient to supplement what has been said already by the following directions:—

The background colours are distinguished from those used with the brush or in printing. The former must be somewhat liquid; they are used either for colouring the whole piece, taking the place of a slip, or else to colour only certain parts, such as the edges of plates, or for making bands. The putting on of them is somewhat difficult if a uniform tint is desirable. Besides, for deep colours it is necessary to make them very thick, and to run the risk of their not being entirely dissolved by the glaze, in which case they remain dull and are liable to be detached from the body.

The colours put on with a brush or printed on are more

numerous and need fewer precautions. As in the preceding ones, the composition of them depends on the temperature at which the glaze fuses; also it is wise, when the temperature is rather a high one, to try and give them such compositions as are sufficiently stable to be able to resist the action of the silica as much as possible. They are often mixed with a certain proportion of the body, especially when they are for porcelain.

**192. Coloured Glazes.**—The colour, instead of being put into the bodies or on the surface of them, may be embodied in the glaze, which thus becomes a coloured glass. This method of colouring pottery is the one that gives the most brilliant colours.

Coloured glazes are prepared like ordinary glazes, but with the colouring matter added to them. According to the colour used, they must be alkaline, boracic or plumbiferous. After having been finely powdered, water is added to them in such a way as to make a paste of the desired consistency. They are almost always put on the burnt body or else on one that has been warmed through, either covered with slip or else without.

If the whole ware has to receive a uniform layer of glaze, the latter is put on by one of the processes used for putting on colourless glazes (Art. 142), specially using for it either that of immersion or of dusting, the body having been first coated over with gum arabic or with some other viscous material.

When using these methods, certain parts that are intended to have a special decoration must be left out. Different methods are used for these *reserves*, the two simplest being as follows: the parts to be left out are covered, by means of a brush, with a coating made of chalk and spirits or gum, then the whole piece is dipped into a coloured glaze, and heated sufficiently to make the glaze adhesive. The painted parts that have not adhered to the body fall off of themselves, leaving the reserve bare.

When these reserves have to be ornamented with glazes of different colours from those of the background, they can be first put on with a brush, after having been mixed with oil; at the time of dipping, the glaze of the background, which is prepared with water, does not adhere to the greasy parts. When the glazes are transparent, it is sometimes difficult, in dipping, to

get a perfectly regular thickness, though this is necessary for giving the whole piece a uniform colouring. In that case it is preferable, especially when required for large surfaces, to employ the method of putting on that has been described under the name of spraying (Art. 142).

At other times, on the contrary, it is advisable to try and get different thicknesses in the glaze, so as to obtain darker or lighter shades. For this purpose, the body has hollow ornament that is obtained in the moulding, or else by engraving on the body afterwards. When it is being applied by spraying, the thickness of the colour can also be varied.

Coloured glazes, naturally, can also be applied with a brush on the burnt or warmed body; but if they are put side by side, they have a tendency to mix together when they are vitrified. To prevent this trouble, they begin by tracing the edges of the design with a black glaze that is less fusible, of a fairly high relief. The cells thus made are afterwards filled with different colours. The ware decorated by this process has been called *cloisonné enamel* ware, in consequence of its likeness to certain enamels on metal.

**193. Over Glaze Colouring.**—Lastly, colour can be placed on the glaze, either before the latter has been burnt or after it is vitrified. In the first case the glaze is nearly always an opaque, white enamel, which, at the moment of its vitrification, dissolves and fixes the colours; these must naturally be able to resist the temperature for burning. In the second case the colours ought to be added to fluxes, that is to say, must be vitrifiable colours, which change to glasses at a temperature for burning below that of the glaze to which they adhere.

The application of the colours on the *raw enamel* can only be done with a brush and needs great skill, because of the thinness of the glaze. The colouring matter is diluted with water, to which is added glycerine if they are absorbed too rapidly. It must be observed that, the glaze being nearly always stanniferous or plumbiferous, it is wise to take account of the action that the oxides of tin and lead may have on the colouring matter. The reduction of the number of shades that there are in consequence of this, added to the difficulties of application,

make this kind of decoration very little used, in spite of the harmony and depth that is given to the colouring.

*Over glaze painting with vitrifiable colours* is, on the contrary, a method of decoration which is very much used, not only in potteries but also by amateurs. Thanks to the low temperature at which the fluxes vitrify, an extremely rich pallet of colours is possible, and at the same time all the numerous difficulties are avoided that are presented by the other methods of colouring which have just been described. It is only fair to add that the colours are usually rather dull, and that the decorative effect cannot be compared with that of the colouring for hard firing.

In order to manufacture *vitrifiable colours*, a suitable mixture of the colouring materials must first be made. They are usually combined together by dissolving the colouring oxides in hydrochloric acid, and precipitating them with carbonate of soda. The precipitate is washed, dried, and then calcined at a red heat.

On the other hand, the flux is prepared, and this is a compound of white sand, red lead and borax in varying proportions. The mixture is melted in a crucible, and run off as soon as it is completely fused. When cooled, it is mixed in a suitable proportion with the colouring matter, and the whole powdered very finely.

The most important pottery factories make their own vitrifiable colours, the others buy them all prepared.

For *over glaze painting* the vitrifiable colours are usually mixed with spirits of turpentine. They are applied with a brush, proceeding in flat layers over one another, as in water-colour painting. To obtain dark colours it is sometimes unavoidable to give to the layers thus put over one another such a thickness that the colour would scale off in firing. Then the piece is put a first time into the kiln, then it is re-painted on the vitrified colour and burnt again. This operation can be repeated several times, until the desired effect is obtained.

The backgrounds in a single shade can be painted in the same way, but with a badger brush, and the layer is afterwards stippled up with a short-haired or polecat brush. The piece can also be coated with boiled linseed oil, with the addition of a

little resin, on which the dried and powdered colour is applied by dusting.

The merchants of vitrifiable colours sell the colours ready prepared for amateurs, so that it is easy for anybody, no matter who, to think himself a pottery painter, by buying a white plate or vase, painting it and having it burnt.

When a large number of similar objects have to be decorated printing is resorted to. For this purpose is used, either the method of printing in monochrome already described, or else *chromo-lithographic printing.* For this, they begin by tracing the original design in outline with lithographic ink and transferring it to stone. This first transfer makes it possible, by the ordinary process of lithography, to produce a sufficient number of copies, which are themselves transferred to as many stones as there are different colours. The draughtsman then, following the outlines thus produced, traces with a brush, in lithographic ink, the parts which have to be coloured, each stone, naturally, being painted only on the parts corresponding to its colour, the rest of the tracing being afterwards wiped off. This done, the stones are washed over with acidulated water, which fixes the ink and gives a slight relief to it. By afterwards passing over the surface of the stone with a wooden roller, covered in leather and soaked in varnish, the varnish is left on the parts covered with ink. Then a sheet of paper, sized with gum arabic or dextrine, is taken, spread on the stone, and the whole passed through a printing machine. The paper is covered with the varnish, is raised, turned over and dusted with vitrifiable colour. After the varnish has been allowed to dry, the surface of colour is taken off with a soft brush, and the same process is gone through in printing the second colour. According to the number of shades to be obtained, this operation is repeated a greater or less number of times, care being taken each time, naturally, to repeat exactly the position of the sheet of paper, so that the different colours should occupy exactly their right places. Usually each design is reproduced several times on the same stone in such a way as to use all the surface. In some factories, the lithographic stones are replaced by suitably prepared zinc plates.

The chromo-lithographic sheets thus manufactured are kept until wanted to be used. They can also be bought.

The transferring of the colour on to the ware is done in a very simple way. The design having been covered over with copal varnish and resin dissolved in spirit, it is applied to the ware, first with a roller, then by stippling, so as to get out any air bubbles. After having allowed the varnish to solidify in the air, the pottery is plunged into water, which dissolves the gum or dextrine from the paper; this paper comes off by itself, leaving the colour sticking to the ware. The piece, after having been washed, is dried in the air, heated in a stove to evaporate the varnish, and then put into the kiln.

This chromo-lithographic process is used specially for ornaments and flowers, but it gives moderately good results for subjects representing animals and figures. In that case it would be better to use *photo-lithography*, that is to say, by using photographs in the place of original designs. Without entering into special details, we will simply say that the problem consists in transferring the modelling and the half tints of the photograph into a sort of engraving that can be reproduced by printing. Several processes can be used for this purpose. The simplest, which generally gives results that are satisfactory for pottery printing, consists in exposing to the light a plate of bichromated gelatine, covered over with a proof of the photograph that it is desirable to reproduce. When the length of the exposure has been satisfactory, the surface of the gelatine plate is inked by means of a printing roller, then covered with a sheet of paper, the whole put in the press, and thus a reproduction of the photograph is obtained on the paper; this is afterwards transferred on to stone and treated in the same way as in the ordinary process of chromo-lithography.

The colours thus obtained by printing on the glaze are, as we have already said, rather dull, especially so on account of the small quantity of colouring matter that it is possible to fix by chromo-lithography. Sometimes it is attempted to make them more brilliant by burnishing them after they are burnt, with a stipple and very fine sand. This process, which is long and costly, may be replaced by a mechanical arrangement, in which

the ware is pressed against the brushes, moved round and round very rapidly, adding emery powder to it.

**194. Decoration with Metals.**—The metals that can be used in a metallic state for decorating pottery, are gold, platinum and silver. They are, in fact, the only ones, that, while being malleable, resist the action of oxidising and heat.

Metallic gold can be used *under glaze.* In that case a sheet of gold is cut decidedly thicker than those intended for gilding, in such a way that it will take the form of a part of the decoration, and it is fastened to the burnt body by means of resin or with a decoction of quince pips. To give it a brighter look in decoration, the body can be first covered with a thin glaze, dusted over with grains of sand, which, when burnt, is covered over again, as we have just said, with gold leaf, and this is stippled with a short-haired brush, which gives it a granulated surface. The glaze is applied afterwards and burnt in the ordinary ways. The gold must not contain any copper, as this would oxidise and would soak into the glaze and colour it green. It must be noticed that the temperature for vitrifying the glaze must be below the temperature for fusing the gold, that is to say, below 1,045° C.

Platinum can be used in the same way. Silver, being more easily oxidised and more fusible, is more difficult to use.

The preceding method of decoration is only used in exceptional cases, while, on the other hand, *over glaze gilding* is very frequently made use of, one might even add, too frequently so. In that process the gold is no longer in the form of leaf gold, but it must be reduced to an impalpable powder. For this purpose it is dissolved in aqua regia, and afterwards precipitated, either with a dilute solution of sulphate of iron, or by a solution of protonitrate of mercury. In both cases a precipitate of metallic gold is formed, and this is separated from the liquid by decanting, washed several times in boiling water, then dried at a temperature below 100° C. Powder gold prepared with mercury is more bulky, and consequently more economical and more used than that from protoxide of iron, which is more dense and solid.

For fixing the powder gold thus obtained on the ware, it

must be mixed with a flux. For this a solution of nitrate of bismuth in nitric acid is employed. This salt being precipitated by water, about $\frac{1}{12}$th of borax is added to it, and the mixture dried, then it is added to the gold powder in the proportion of $\frac{1}{12}$th or $\frac{1}{15}$th. In certain cases a little borate of lead is added to it to increase its fusibility.

After being burnt, the vitrified gold has a dull look, which can be brightened by burnishing it with agate burnishers, or else hematite or bloodstone ones, or with fine sand. It is best to rub it always in the same direction, so as not to scratch the gilding, and to add some liquid, such as vinegar for example, to make the rubbing softer, when burnishers are used. Certain parts may be burnished, so as to obtain effects of contrast between the dull and bright gold.

*Platinum* can also be used over glaze in the same way as gold. With this object it can be dissolved in aqua regia, and precipitated by means of carbonate of potash and sugar, or by caustic potash with the addition of alcohol. The precipitated or black platinum is dried, then calcined at the commencement of a red heat, and used as has just been described for gold. As for *silver*, it is obtained in the form of a powder by precipitating the chloride with zinc, and adding sulphuric acid to it. The nitrate also can be decomposed by means of a copper wire. The precipitate thus obtained is dried and used in powder the same as gold.

The preceding metals can also be mechanically reduced to a powder by grinding them on a glass with some honey. This process, which has been used for manufacturing gold called *Dutch gold*, is very troublesome, therefore it is now scarcely ever used.

**195. Decoration with Metallic Lustres.**—The lustres are formed of a very thin layer of metal, very finely divided; this takes a metallic shine with iridescent effects when it has been heated at a rather low temperature, without which it is necessary to burnish it. The metals used are gold, platinum, silver, copper, iron and lead. The lustres are always applied over the glaze, and the more brilliant the latter, the more the lustres shine. There exist numerous recipes for obtaining decorative effects

very cheaply, but we will only mention those that are most used.

*Gold Lustres.*—The best known of these lustres is *bright gold*, which, when burnt, has a metallic brightness, but it resists wear less than dull gold that is made bright by burnishing, as we have just described. This method of decoration, also known by the name of *Meissen gilding*, is done with liquids that are sold by certain colour merchants; these carefully keep their recipes as manufacturers' secrets. Thanks to competition, the prices have gone down so much that potters really do better to buy the lustres than to try and manufacture them themselves.

The first thing is always to dissolve the gold in aqua regia, only, instead of precipitating the gold from the chloride thus formed, they try to separate this chloride in solution from the acid liquid, and to incorporate it in a mixture of spirits of turpentine and sulphur. For this purpose, after having added a little tin to the acid solution, it is slowly poured into a mixture of sulphur or balsam of sulphur and spirits. A yellow, viscous liquid is formed with greenish tinges, while the acid liquid which floats on the top is taken off by decanting. Rectified ether can also be mixed with the solution of chloride of gold, and this seizes on the chloride and floats on the top of the acid liquid, which is drawn off. The ether liquid can then be added to, by the mixture of sulphur and spirits. However it is done, the mixture becomes of the consistency of syrup, then a flux of bismuth is added, as in gilding, and lastly it is diluted in a sufficient quantity of spirits of turpentine or spirits of lavender, so as to be able to be applied with a brush.

*Fulminating gold* can also be used; this is obtained by precipitating chloride of gold with ammonia. The chloride of gold is made by dissolving gold in aqua regia. A yellowish-brown precipitate is produced; this is separated and ground, while still damp, with the essential oil of turpentine or else with spirits of lavender. It is applied directly on to the ware without being mixed with a flux. The precipitate must be prevented from drying at all costs, otherwise it would explode violently with the least touch.

Lastly, gold is used for preparing the lustre known as *burgos*,

which only differs from the preceding lustres in that a larger quantity of spirit is used and less gold. The solution in aqua regia for this purpose may have the addition of 20 per cent. of metallic tin.

*Platinum Lustre.*—The chloride of platinum obtained by dissolving that metal in aqua regia may be used directly in decoration. It is sufficient, after having concentrated the solution, to add an essential oil, spirits of lavender for example, and to spread the liquid on the ware with a brush. The lustre obtained has a steely appearance, but has the disadvantage of being nearly opaque.

Thanks to the unchangeableness of the metals used, the preceding lustres can be burnt with an oxidising firing. It is not the same with the following ones, which, on the contrary, must be fixed in an atmosphere that is very distinctly reducing.

*Silver Lustre.*—Chloride of silver must first be vitrified with a plumbiferous flux till it is like crystal; this makes a more or less yellow glass, which is powdered; and some spirit, and sometimes bismuth, is added to it, then it is applied with a brush. When burnt it gives the ware either a metallic look with yellow reflections, or a very rich iridescence, which has given it the name of *cantharides lustre.*

*Various Lustres.*—Lastly, a whole series of lustres can be manufactured which contain the salts of silver, copper, iron and lead. According as one or other of these metals preponderates the lustre has different reflections. Copper gives a golden colour, silver a steely tinge, iron produces red. The metals are usually in the form of sulphides, and sometimes a little lampblack is added to them to help in reducing them. The colours are thinned either with vinegar or with thick spirit, and then applied with a brush. Certain colour merchants sell a whole series having the most varied reflections.

**196. Various Methods of Decoration.**—Among the numerous different processes of decoration which have been used, and which cannot besides be classified, the following may be mentioned:—

*Crackling.*—The defect which has been mentioned by the name of crackling, which arises from the relative contraction

of the glaze being greater, may be made use of as a means of decoration. In that case the antagonism between the body and the glaze must be fairly great, so that the latter should be cracked in a great number of little lines, forming a regular network that is larger or smaller. The ware can then be covered again with a second coloured glaze, that is more fusible, which would penetrate into the cracks and make them stand out by their different colouring. This method of decoration, in which the Chinese excel, is called crackled.

*Streaks.*—We have seen that, in consequence of too long a baking or too high a temperature, the glaze may run down. This defect also has been made use of as a means of decoration. In this case are used glazes which have been made more fusible by having a fairly large proportion of borax introduced into them; they are usually coloured, and applied either on the burnt body or on another more refractory glaze. Marbled effects, which are more or less unforeseen, are thus obtained.

*Flamed.*—This process of decoration also consists in an intentional use of a defect. We know that certain colouring materials change colour according to whether they are burnt in an oxidising or reducing atmosphere. With oxide of copper especially this is the case. In the form of a protoxide, that is to say, when burnt in a kiln with an oxidising working, it has a green colour in boracic and plumbiferous glazes, and blue in alkaline glazes. On the other hand, in the form of a sesquioxide, that is to say, in a reducing atmosphere, it gives a red colour. By alternating the composition of the atmosphere, a succession of oxidising and reducing effects can be produced, so that the ware can have changing, capricious colours, which are quite as though unforeseen, more so still if the temperature is rather high; the oxide of copper in that case may partially volatilise, and let the body showing through the glaze appear uncoloured.

*Flowing Colours.*—If the wares decorated with a design of certain colouring oxides are heated in an atmosphere containing volatile chlorides, the latter may attack the metallic oxide and also change it into a volatile chloride. This

chloride, by taking the colour from the design, spreads on to the surrounding white body, is decomposed there by contact with the silica, giving it a light, graduated tint, darker in the neighbourhood of the design and forming a sort of halo round it. The chlorated atmosphere is usually produced by putting a vessel on the top of the pile of saggers, containing a small quantity of chloride of lead, which has been obtained by dissolving white lead in hydrochloric acid. With the paste thus obtained, little balls, about $\frac{1}{2}$ inch in diameter, are formed, which are dried and placed in the vessels that have been first coated with lime, to prevent their fusing by contact with the lead. When the glazes employed are very plumbiferous, and when it would be inadvisable to increase the amount of lead in them, a mixture of six parts of sea salt and four parts of saltpetre can be made use of, these giving off alkaline chlorides.

The principal colouring oxides which thus form volatile chlorides are oxide of cobalt, either pure or in its different combinations, which produces a low toned blue; oxide of nickel, giving brown; oxide of copper with a low temperature, producing green; and, lastly, oxide of iron, which gives a yellow that is not very agreeable. This process of decoration is used almost exclusively for earthenware; it is useless to add that, for success, it is necessary to lute the saggers carefully.

The following processes of decoration, on the contrary, resemble those which have been described.

After a coloured glaze has been applied, and when it is dry, it can be taken off in places, or it can be *engraved* in such a way as to let the body or a glaze underneath show. The friability of the raw glaze makes this operation very easy to do, nevertheless it is necessary for it to be done with a certain amount of dexterity, so that more glaze is not taken off than is wanted.

An effect of *being covered with pearls* on the surface of a piece of pottery can be got by first covering it with a thin layer of a colourless glaze, over which, while still damp, grains of sand or of burnt ware powdered coarsely can be dusted. When burnt, the surface is coated again, spotted thus, with another glaze which forms around each grain a little vitreous

drop, which has more or less the look of a pearl. By replacing the sand by some of the body more finely granulated, a decorative effect is obtained that has been called *moss*.

With the same kind of idea, small glass objects—*pearls*, *spangles*, *jewels*, etc., can be fixed on the body or on a first glaze, by means of a greasy spirit, with some flux added to it.

The burnt bodies can be decorated with designs that seem to have been done with a black lead pencil, or with the coloured paste used for drawing in pastels. For this are used *vitrifiable crayons*, that is to say, vitrifiable colours enclosed in wood, which are used like ordinary pencils, only they must be sharpened by rubbing them on glass paper. These vitrifiable crayons were invented by M. A. Lacroix, the eminent chemist to whom we owe the introduction in France of the industry in vitrifiable colours.

We may also mention again the decoration by means of photography, that is to say, of ceramic photography, which must not be confounded with photo-lithography, of which we spoke before.

The process of which we are now speaking lends itself to reproduction. A sheet of ground glass is taken, covered with bichromate of potash, dextrine and grape sugar dissolved in water, and exposed to the light in a positive frame. If a negative frame is used, the sheet of glass must be covered with an aqueous solution of perchloride of iron and tartaric acid. After having allowed the proof thus obtained to absorb the humidity from the air, it is dusted over with a vitrifiable colour. The developing finished, the excess of colour is taken off, the glass is coated with a layer of normal collodion, and plunged into some slightly acidulated water. The collodion comes off, taking with it the vitrifiable colour, and is applied to the ware. If the collodion is placed underneath, it need only be dried and burnt; if, on the other hand, it has been applied to the ware on the side where the colour is, then the collodion must be taken off with a solution of alcohol, ether, and spirits of lavender.

Lastly, there is a whole series of processes for decorating pottery without using heat, which may be called in general terms *cold decoration*. Pottery, or no matter what other substance, can, in fact, be coated with ordinary paint, varnish,

lacquer, etc. Without desiring absolutely to condemn this kind of decoration, as some people have done, we will content ourselves with remarking that it does not belong to ceramics; therefore we will not enlarge upon this subject.

**197. Burning the Colours.**—What has been already said in relation to burning the bodies and glazes will naturally apply to the burning for colours. As with colourless glazes, first must be studied the agreement between the body and the glaze, and the directions already given must be followed. The maximum temperature for burning, as well as the working of the fire, must be the object of a most minute attention. In theory, it is wise not to expose the colours too long to the temperature for fusing the glaze or flux, because of the ease with which some of them volatilise. We know that this volatilisation is increased in great proportion when the wares are charged by the side of unglazed bodies. It is still more to be feared for over glaze colours or for coloured glazes than for under glaze colours. Lastly, the metallic oxides on a piece may soil a neighbouring piece, when the charging is too close together, or when the pieces are of different colours.

When the temperature for burning is very high, the charging is done in saggers in ordinary kilns; in all other cases muffle kilns are used with charging on slabs. For burning vitrifiable colours, which is done with a relatively low temperature, the fireclay slabs for charging them can be replaced by iron plates. Besides the methods for measuring the temperature already described (Art. 180), *the tests for gold* are often used for burning these vitrifiable colours. These tests consist of a test of the body covered with a gold colour fairly thick, the colour varying with the temperature, as is shown by the following table:—

| Colour of the Test. | Approximate. Temperature | Observations. |
|---|---|---|
| | Degrees. | |
| Red brown . . . . . | 650 | Burning lustres. |
| Red . . . . . | 800 | ,, |
| Rose purple . . . . . | 900 | Burning vitrifiable colours. |
| Rose violet . . . . . | 920 | ,, |
| Violet . . . . . | 950 | ,, |
| Pale violet . . . . . | 980 | ,, |
| Colourless or only slightly violet . | 1,000 | Burning dull gold. |

The working of the muffles for burning colours ought nearly always to be oxidising, and it is advisable to prevent any crack by which an entrance of the gases from the fireplace could take place. For the reds from copper and for certain lustres, on the contrary, a decidedly reducing atmosphere is necessary; then a small ordinary kiln is used in preference, in which the ware is charged in open-work saggers.

# SECOND PART.

## SPECIAL POTTERY METHODS.

# CHAPTER IX.

## TERRA COTTAS.

SUMMARY.—Classification.

Sec. 1. *Bricks:* (*a*) *Plain Ordinary Bricks*—Forms and Dimensions—Moulding by Hand—Moulding by Machine—Manufacture by Expression—Manufacture with a Press — Repressing—Drying — Burning — General Arrangements of Brickfields. (*b*) *Hollow Bricks.* (*c*) *Ornamental Bricks.* (*d*) *Vitrified Bricks.* (*e*) *Light Bricks.*

Sec. 2. *Tiles:* (*a*) *Ordinary Tiles*—Forms and Dimensions—Moulding by Hand—Moulding by Expression—Manufacture in a Press with Semi-Soft or Semi-Stiff Body, and with Stiff Body—Drying—Burning—General Arrangements of Tile Works. (*b*) *Black Tiles.*

Sec. 3. *Paving Tiles.*

Sec. 4. *Pipes:* Pipes for Gas Channels—Pipes for Water Courses.

Sec. 5. *Architectural Terra Cottas.*

Sec. 6. *Vases, Statues and Decorative Objects.*

Sec. 7. *Common Pottery.*

Sec. 8. *Pottery for Water and Filters.*

Sec. 9. *Tobacco Pipes.*

Sec. 10. *Lustre Ware.*

Sec. 11. *Properties and Tests for Terra Cottas:* Causes of Disaggregation and the Remedies—Methods of testing Terra Cottas.

**198. Classification.**—We have seen in Chapter I. that terra cotta is porous pottery, not covered with a glaze, the body of which cannot be heated to a temperature above that for burning hard porcelain without losing its shape or vitrifying.

This class contains wares that are very different in form, use and aspect; yet, the characteristics just mentioned nearly always allow of their being distinguished unhesitatingly from other ceramic productions.

In order to distinguish between the different kinds of terra cotta the physical properties of the body cannot be relied upon, as they are usually the same for all; therefore we are obliged

to introduce the differences in form and use. Taking this as a basis, the following are the different kinds of terra cotta which will be studied in this chapter:—

1. *Bricks*, or terra cottas used in constructing the walls of buildings. There are five varieties:—

(*a*) Plain ordinary bricks.

(*b*) Hollow bricks.

(*c*) Ornamental bricks.

(*d*) Vitrified bricks.

(*e*) Light bricks.

2. *Tiles*, or terra cottas used for the outside of buildings. There are two varieties:—

(*a*) Ordinary tiles.

(*b*) Black tiles.

3. *Paving tiles*, or terra cottas, intended for clothing walls or pavements.

4. *Pipes*, or terra cottas used as channels for gas or liquids.

5. *Architectural terra cottas*, generally used for decorating buildings.

6. *Vases, statues and decorative objects.*

7. *Common pottery*, used for domestic purposes.

8. *Pottery for water and filters.*

9. *Tobacco pipes.*

10. *Lustre ware*, the body of which is covered either wholly or partially with a coating called by the name of lustre, midway in look between a slip and a glaze.

## § 1. Bricks.

### (*a*) *Plain Ordinary Bricks.*

**199. Forms and Dimensions.** — The bricks[1] used by the Egyptians, Assyrians and Romans were noticeably larger than those manufactured at the present time; often they were rather in the form of slabs. The following table shows the dimensions of some of the best known types of bricks:—

[1] From the ancient Anglo-Saxon *brice* (a fragment); French *brique;* Provençal *briga* (crumb).

| *Ancient Bricks.* | Dimensions in Centimetres. | | | Volume in Cubic Decimetres. |
|---|---|---|---|---|
| Susiane (Mission Dieulafoy) . . | 30 | 15 | 15 | 6·75 |
| ,, ,, . . | 30 | 15 | 7·5 | 3·38 |
| Roman . . . . . | 59·4 | 59·4 | 5·5 | 19·40 |
| ,, . . . . . | 44·5 | 44·5 | 5 | 9·90 |
| ,, . . . . . | 21·2 | 21·2 | 4 | 1·80 |
| Languedoc (11th and 15th century) . | 33 | 25 | 6 | 4·95 |
| *Modern Bricks.* | | | | |
| *France:* Burgundy . . . . . | 22 | 11 | 5·5 | 1·33 |
| ,, Marseilles . . . . . | 22 | 11 | 5 | 1·21 |
| ,, ,, . . . . . | 22 | 11 | 7 | 1·69 |
| ,, Paris (Vaugirard) . . | 22 | 11 | 6 | 1·45 |
| ,, ,, . . . . . | 22 | 11 | 6·5 | 1·57 |
| ,, largest type . . . | 23 | 11 | 7 | 1·77 |
| ,, smallest type . . . | 20 | 10 | 5 | 1·00 |
| ,, type proposed by the Pottery Union . . . . . | 22 | 10·5 | 5·5 | 1·27 |
| ,, type proposed by the Architects of the North . . | 22 | 10·5 | 6 | 1·39 |
| *Germany:* normal type . . . | 25 | 12·3 | 6·5 | 2·03 |
| *England:* largest type . . . . | 25·4 | 12·4 | 7·6 | 2·39 |
| ,, smallest type . . . | 23·6 | 11·5 | 7·6 | 2·04 |
| *Austria:* largest type . . . | 29·5 | 15·2 | 6·7 | 3·00 |
| ,, normal type . . . | 25 | 12·5 | 6·5 | 2·03 |
| *Belgium:* smallest type . . . | 17·6 | 8·5 | 4·5 | 0·68 |
| *United States* . . . . . | 19·7 | 9·8 | 5 | 0·98 |
| *Mexico* . . . . . | 26 | 13 | 6·5 | 2·20 |
| *Netherlands* . . . . . | 26 | 12 | 5·4 | 1·68 |
| *Switzerland:* largest type . . . | 27 | 14 | 6·5 | 2·45 |
| ,, normal type . . | 25 | 12·5 | 6·5 | 2·03 |

All the bricks are of a parallelopiped form. Only some Roman bricks were triangular.

At the present time, in all countries, there seems to be an agreement to make the bricks with a volume varying between 130 and 59 cubic inches. The length ought to be double the width, reckoning for a joint 0·39 to 0·24 inch. This width must not be more than 4·68 inches, so that a bricklayer can easily take the brick between his fingers when it is lying flat down.

It follows that the length ought to be at the most equal to 9·75 inches. As to the thickness, it must hardly be more than 2·75 inches, so that the drying does not take too long, and must not be less than 1·95 inch if the price of brickwork is not to be increased. The normal German type, on the one hand, and the type proposed by the Pottery Union of France, on the

other, can then be reckoned as the two limits for the most convenient measurements.

**200. Moulding by Hand.** — Ordinary bricks are frequently moulded by hand. For this, rather sandy bodies ought to be used, so that they should not have too great a tendency to stick to the moulds, on account of their consistency, which is necessarily very soft.

The preparation of the bodies usually consists of a simple mixing together (Art. 87). The treading with the feet or by

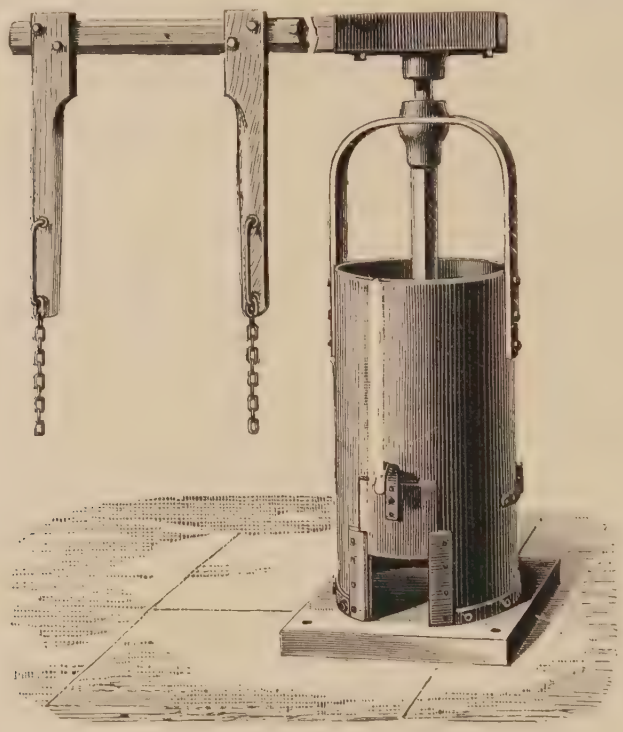


Fig. 189—The Mill for Mixing.

animals ought to be absolutely condemned. As in hand brick-fields there is usually no motive power, the mixers used are worked by an arrangement in which the rod is fastened directly on to the vertical bar. Fig. 189 shows the arrangement generally used.

It is wise to first make the clay of the required consistency by moistening it either in a heap or a pit (Art. 84). If a sandy substance has to be added to it, the amount is put to the

volume at the entrance of the mixer. The production of these mixers varies from 26½ to 53 cubic feet an hour when they are worked by a horse.

The body having thus been prepared, the moulding is proceeded with. This is done on a table before which the moulder stands. We have seen (Fig. 86, page 206) the drawing of a wooden mould. Iron moulds or wooden ones that are strengthened by iron bands can also be used. In some localities two moulds, fitting together, are employed; in others the mould, instead of being a simple framework, has a bottom to it.

To prevent the body sticking to it, the mould is first dipped in a bucket of water, or else well dusted over with sand. The former method gives the bricks a more pleasing look, but they are more liable to split in drying.

In all cases the moulding is done by taking up a slightly larger quantity of the body than is necessary, knocking it sharply into the mould and afterwards levelling the upper surface with a scraper. When the mould has no bottom, it is afterwards drawn to the edge of the table, then, by putting the hand underneath, it is turned over in such a way as to set it on edge. In this position it is raised to carry it on to the floor, where it is turned over again, so that the face that was uppermost at first, is placed on the ground. Thanks to the slight shock that is given to it while putting the mould on the floor, it is easily taken out of the mould by raising the mould up vertically. In some localities the mould, instead of being put on the table, is put on a little board, which is taken up with the mould, it being taken out of the mould on the floor by drawing this board away. If the mould has a bottom to it, it is only turned over when being taken out of the mould on the floor.

The moulders of different countries each have their special methods, to which they are accustomed from childhood, and which it is not possible to make them alter. They work in gangs, composed of the moulder, and one, two, or three women and children, who help to carry the bricks and take them out of the moulds. When preparation of the body is done by kneading, this operation requires one or two more workmen.

The number of bricks made by a moulder depends upon his skill and the nature of the body. Under the most favourable circumstances the number may be as much as 600 to 700 bricks an hour, but then they will be rather defective ones, because the body used is too soft. The more the stiffness is increased, the more the quality improves, and the less the production is.

In order to have bricks of a good appearance and of the best quality, it is necessary to use a body of such a stiffness that it is not easy to take them out of the moulds, when the moulds that we have just mentioned are used. Then moulds that can be taken to pieces are used (called open moulds) which may be constructed in different ways, but the most usual type of which is shown in Fig. 190. In this case the quantity produced is reduced to 150 or 200 bricks an hour.

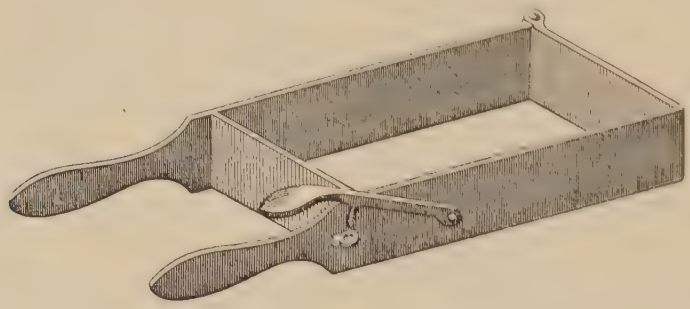


Fig. 190.—Open Mould.

**201. Moulding by Machine.**—In the first machines used for making bricks, the moulding by hand was naturally imitated, as it has just been described. The arrangements made for this purpose have been very numerous, but in spite of very considerable differences in the working and the look of them, the principle was always the same; to introduce a surplus of the body, which was rather soft, into a series of moulds, and to try and compress by causing these moulds to pass under a cylinder, a drum, or some kind of a stone with a rotatory motion. The body was put in by means of paddles, screws and propelling cylinders; sometimes the bottom of the mould was movable, and by raising it the pressure was increased.

All these machines, of which the description can be found in works of pottery of some years back, are no longer used,

or, at least, there is no reason for them to be. In fact it is best to take into account that, with a body of a soft consistency, moulding by hand is the best and most economical method of working. It has the great disadvantage of making the ware impossible to be handled, requiring considerable space for drying it, shrinking very much, and consequently being very porous, and having little power of resistance. If then, in making by machine, a body as soft as that for hand moulding is made use of, the same disadvantages are met with, without any advantage to make up for them. Making by machine is of no use if they cannot be made with stiffer bodies, thus making goods which can more easily be manipulated, piled up, and dried, and which are at the same time of a better quality.

From an economical point of view, except in some exceptional cases, the direct expenses of working will always be higher if machines are used, but, on the other hand, the total expenses of the manufacture can be lessened by the arrangements being well considered, by having suitable raw materials, and then the buyer pays the extra charge which is demanded by a better quality. At the present time there are only two methods of machine moulding for plain bricks: the expression of them from half soft or half stiff bodies, and moulding in a press of a body that is more or less dry.

In some cases the bricks made, either by hand or by expression, may be worked over again in a press, to which process the name of repressing is given. We will now examine these different processes more in detail.

**202. Manufacture by Expression.** — When being made by expression, the stiffer body must necessarily be more plastic than for hand moulding. It is prepared as was described in Chapter III. (Art. 84 and following ones); it usually consists of a mixing and a making it homogeneous, first by rolling and then by being worked up together. Nearly always a single machine is made use of for preparing the body and manufacturing the things as well.

The dies (Art. 102) are, at the present time, nearly always lubricated with water. The bar of clay that exudes may have

a size and thickness corresponding to the length and breadth of the brick. It is then sufficient to cut it into pieces of the thickness desired for the bricks. The dies of this kind, called *cross cut*, make bricks that are smooth on all the surfaces that are likely to be seen, while the two large surfaces that receive the mortar are roughened by being cut with a metallic wire. In some cases the bar of clay is the size of the breadth and thickness of the brick, the cutting then being done at intervals equal to the length.

In the same way a greater breadth can be given to the bar of clay, and it can be cut afterwards when it comes out of the die, by means of several wires stretched across, as shown in Fig. 191. The space between these wires is equal to the

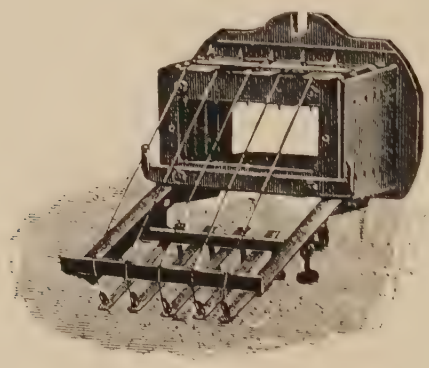


Fig. 191.—Die for Plain Bricks.

thickness of the brick, the height of the die equal to its breadth, so that it is necessary afterwards to cut the bars that are side by side into pieces equal to the length. With this die, termed *longitudinal cut*, there are only the two long surfaces that are smooth, all the others, being cut by wires, are rough, because generally two bars of body side by side, about three-quarters of an inch thick, are taken off, so that the two end bricks do not have one smooth face and one other a rough one.

As regards the dies, in a general way it must be remarked that, the body not being very stiff, the goods, by rolling afterwards on the cutting board, and while being taken to the

drying ground, have a tendency to sink down by their own weight. It is best, when possible, to slightly diminish the dimensions of the lower parts of the die so as to counteract this change of shape.

Among the five classes of *propellers* used in pottery (Art. 103) those with pistons are not used for making plain bricks, on account of their small delivery. As to *propellers with blades*, Fig. 77 (page 201) shows an arrangement used in the case where the motive power is furnished by a horse-gin. A similar machine with a larger output, having two draw plates, set in motion by an underground power, is constructed by M. Schlikeysen. The output of this style of machine varies, according to the one used, from 700 to 4,000 bricks an hour (22-11-6cm.), with the expenditure of from 5 to 20 horse-power. We see that there are no rolling mills, and that if there were, they ought to be placed by the side, the rolled body being automatically introduced into the machine for working it up by means of an endless band.

The *screw propellers* are most used, and the inventing of them has made a great advance in the machine making of plain bricks. It is seldom that the screw is used for the propeller alone, it is nearly always arranged in such a manner as to serve at the same time for a horizontal mixer.

For this purpose the hinder part of it is composed of movable and fixed paddles, a description of which has been given in Art. 87; these act as a mixer, while the front part of it has a regular helix form (Fig. 78), and serves as a propeller.

The dimensions of these different parts, the inclination of the passage, and the speed of the rotation must be suited to the stiffness and the plasticity of the body. The most suitable consistency is that of a half firm body, which allows of five to ten rows of bricks to be piled up on coming out of the machine. If it is weaker, then it has the disadvantages of bricks moulded by hand, which have just been pointed out. If it is stronger, the power expended becomes very considerable. As to its plasticity, it ought to be sufficient for the body to take a regular shape, without being torn about when it comes out of the draw plate; but when this state is reached,

it is wise not to pass it, as a too plastic body has the same disadvantages as a too stiff body, that is, an abnormal increase of necessary power is caused or a considerable diminution in the output.

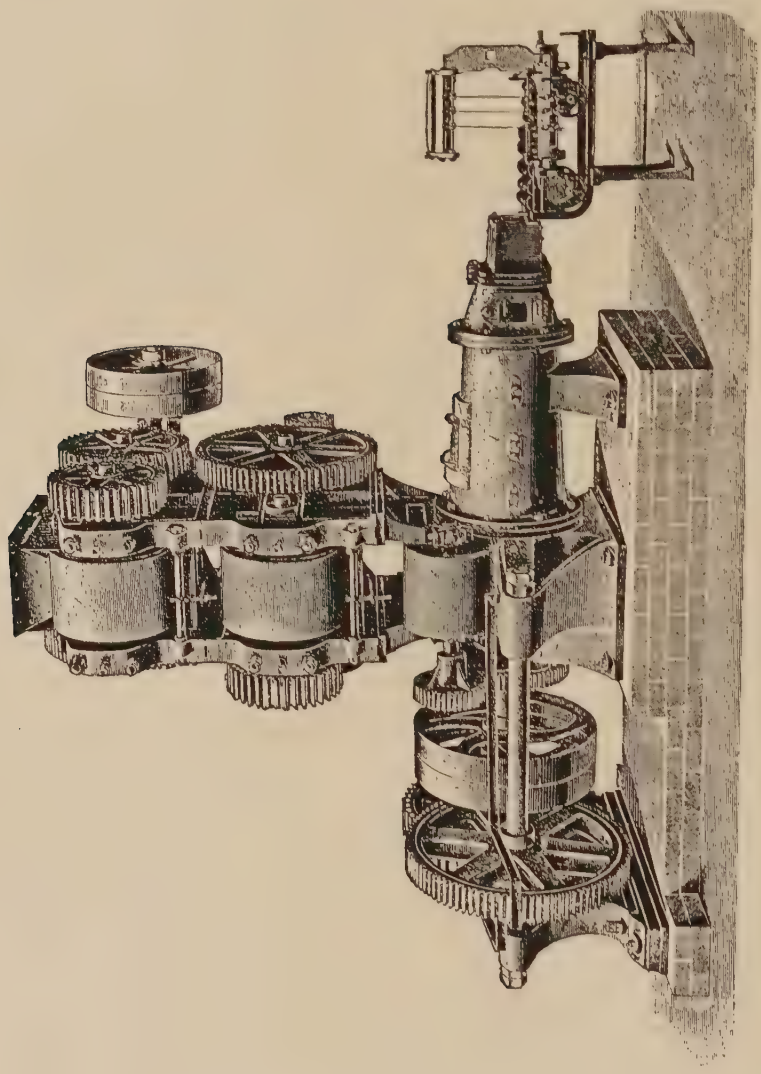


FIG. 192.—Brick Machine.

When the body does not contain kernels or stones it can be put direct into the working-up machine; in other cases it must first be rolled, and for this very often a working-up machine has a pair of rollers fixed above it.

Figure 192 shows a machine that is much used in Germany. It is arranged to work up the more difficult bodies that

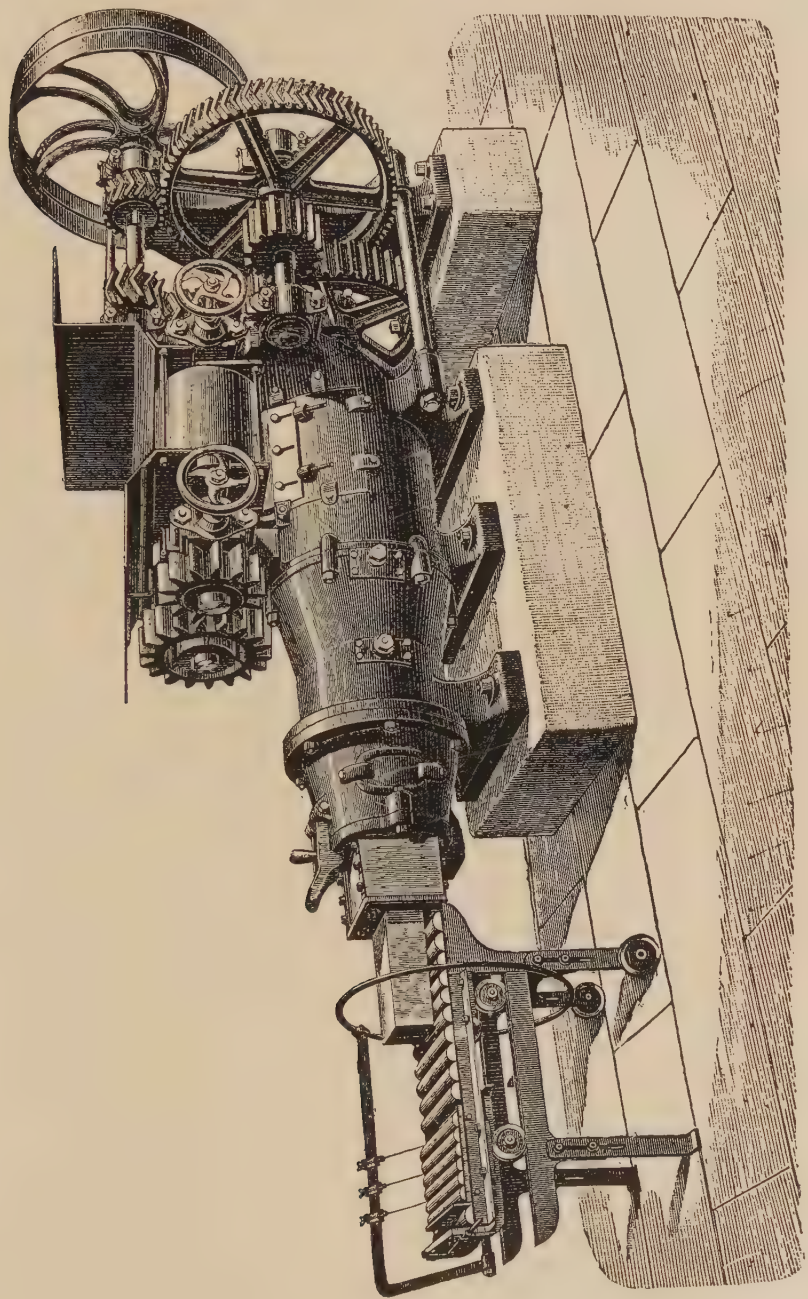


Fig. 193.—Brick Machine.

need two rollings. It will be noticed that there is a fifth cylinder placed immediately over the screw; the object of

that is to push the body against the blades, which, by their rotation, move in an opposite direction from that of the screw. The output of these machines varies from 1,000 to 4,000 bricks an hour for from 10 to 30 horse-power.

Figure 193 represents a machine of the same kind, constructed by MM. Boulet et Cie. In this one the rollers are placed directly over the working-up machine in such a way as to push the body into it. According to the size, these machines produce from 500 to 2,000 bricks an hour, for an expenditure of 4 to 15 horse-power.

A large number of machine manufacturers make similar machines, taken from the type invented by Hertel, which only differ from one another in the construction of the details. Yet some of the machines, instead of having only one die plate, have two, placed side by side and more or less inclined to the axis of the screw. In principle, this arrangement, by making the passage of the body more difficult, increases in a large proportion the power expended, therefore it is not to be recommended.

As the last example of a screw machine, we may mention that constructed by Messrs. Chamber Brothers & Company, of Philadelphia, shown in Fig. 194, which differs from the preceding ones and shows some interesting peculiarities. The rolling is done, if there is any, by rolling machines placed on the ground, and joined to a high hopper, which is over the mixer, by an endless belt. A small cylinder, with a quadrangular section, forces the clay against the blades of the screw. This, which is shown on the plate, supposing the body of the machine to be transparent, is composed of two quite distinct parts. One, in the cylindrical body, is a mixer with blades; the other is a truncated, helix-like propeller. The bar of clay has for its width and height the width and thickness of a brick. It comes out of a die, the walls of which are heated by steam, thus giving the surfaces a kind of lubrication. A hopper, placed above the outlet, contains sand, which is dusted on to the bar of body by means of a separate mechanism. Lastly, a safety-valve, kept in place by a counter-weight, prevents the pressure on the body from going beyond a certain

limit. The output of this machine may reach 4,000 bricks an hour.

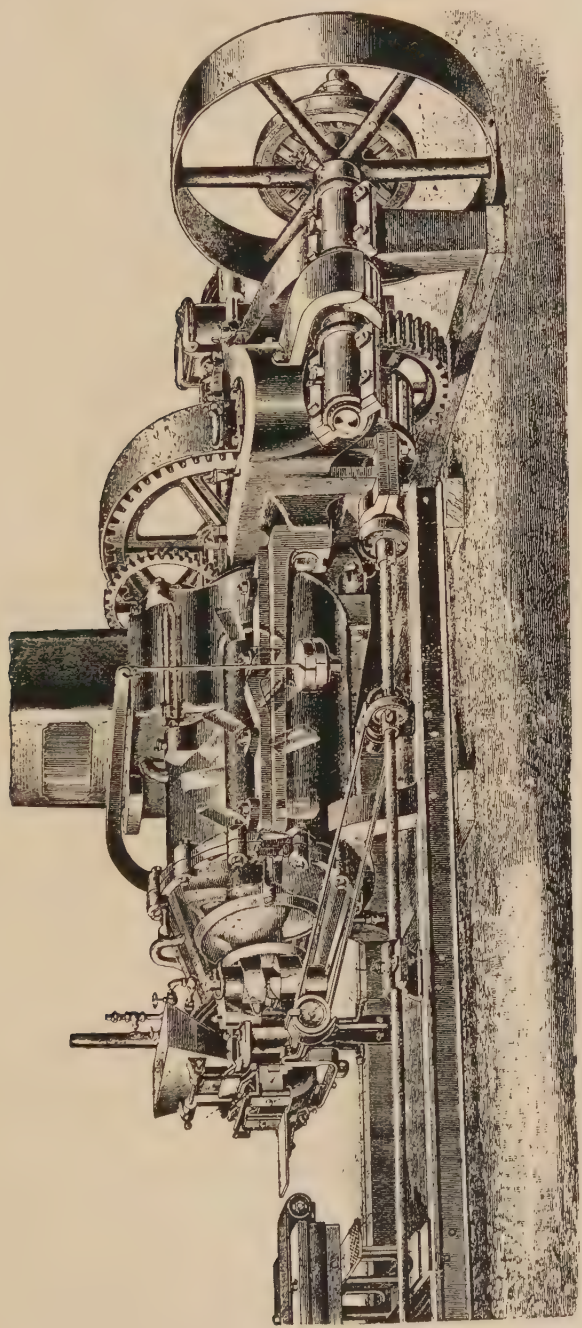


Fig. 194.—Brick Machine.

In all these machines that work continuously, *movable cutting apparatus* ought to be used (Art. 104), such as those

shown in Figs. 192 and 193. In these the wire, while crossing the clay, has a tendency to tear the edges as it goes out. This trouble can be remedied by placing two wires, as shown in Fig. 195, which represents a cutting apparatus constructed by M. Groke. The wire placed vertically describes a circle the same as in the other machines, while the sloping wire makes a groove in the hinder and underneath parts of the bar of the body.

The cut bricks are raised from the board either with the

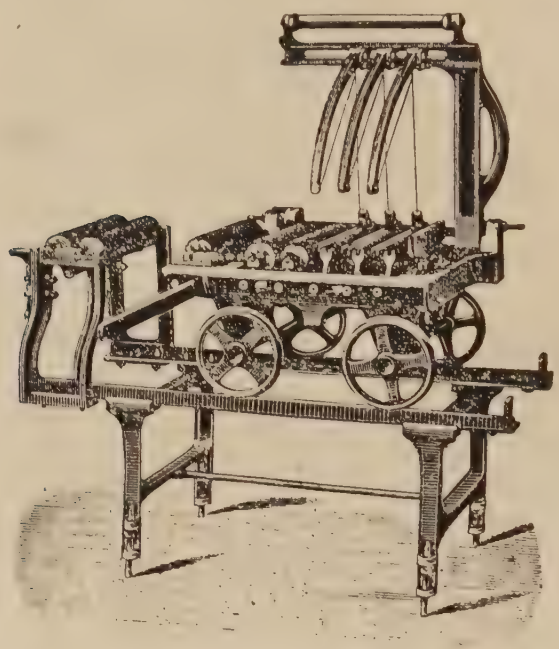


Fig. 195.—Cutting Apparatus.

hands or by sticking two or three pronged forks into them. It is this part that limits the output of the machines to 2,500 or 3,000 bricks an hour at most.

They have tried to cut the bricks automatically, and several arrangements have been proposed with this object, but, for the most part, without any satisfactory result. We must, however, mention the process invented by Messrs. Chamber Brothers & Company, which, notwithstanding its complication, is at present the best solution of the problem. As shown in Fig. 196,

which is a continuation of Fig. 194, the bar of clay is received on an endless band, which moves with a speed equal to that at which the body comes out. This speed is regulated by

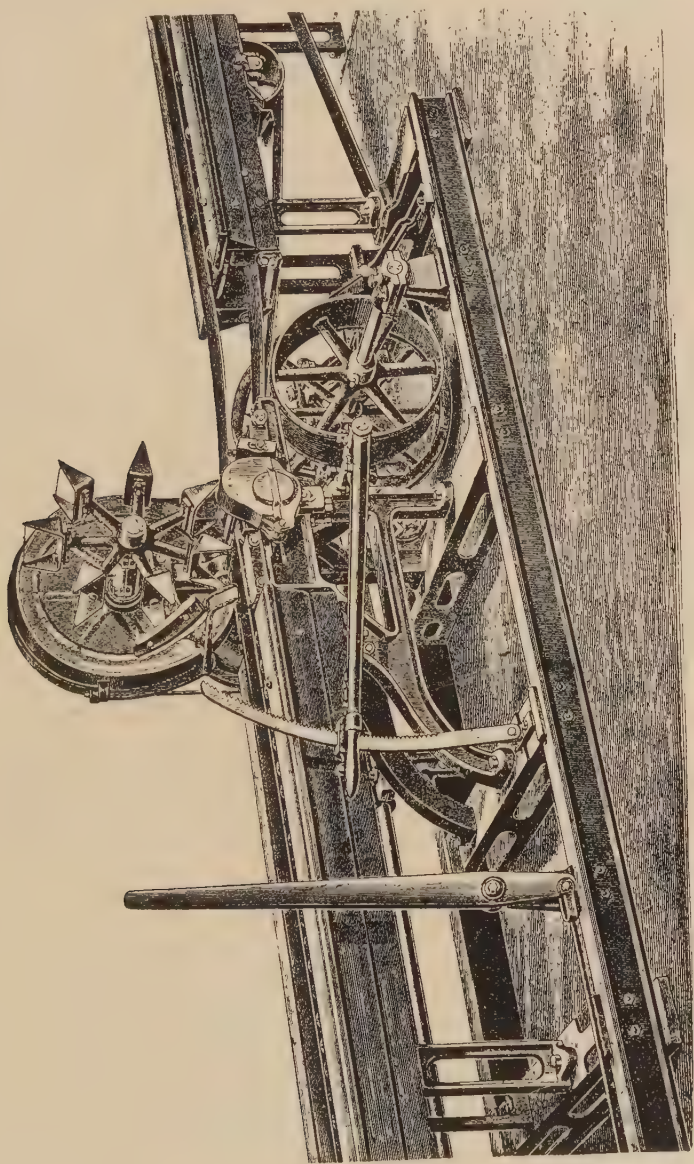


Fig. 196.—Cutting Apparatus.

means of a sloping lever: the vertical lever, shown at the left of the drawing, is used for unfastening it. At the end of this endless band there is a vertical wheel, which turns with a

speed corresponding to that of the band, and is furnished with seven arms carrying wires, which, by their circular movement, cut off the bricks at the desired length. The bricks when thus cut off are pushed on to a second endless band, that moves more rapidly, so that they are separated from one another, and they can afterwards be taken up separately by a series of workmen, who stand by the table on which this second endless band runs. Thanks to this process, as many as 200 bricks a minute can be made.

The *propellers with two screws* that were mentioned on page 203 have been used fairly often in the manufacture of plain bricks. We have already said that the working-up of the body done by two tangential screws is not very good, and that the goods when they come out of the die plate are sometimes imperfectly stuck together. These machines are always surmounted by a pair of rollers, the object of which is to roll the body and divide it into pieces that can be caught hold of by the little helix of the screws. As is seen in Fig. 197, which represents a machine of this kind constructed by MM. Boulet et Cie, the whole arrangement is very much the same as in machines with one screw. Their output varies, according to size, from 600 to 1,500 bricks an hour for an expenditure of 3 to 10 horse-power.

As to *propellers with cylinders*, although they are more logical than the preceding ones, they do not seem to give good results in the manufacture of plain bricks, except by using soft bodies. Besides, it can easily be understood that the passing from a large and very thin section, like that which exists between the cylinder propellers, to a section that is almost square in the die for plain bricks, will only work comfortably when the body is a plastic one, and not at all stiff.

**203. Manufacture with a Press.**—We have seen that the manufacture of bricks in a press is now done almost exclusively with a dry body. That is to say, that the raw materials are in the state of a more or less damp dust, and not in the form of a paste, in the ordinary meaning of the word. The goods thus obtained have a granular look, and need more burning

to replace, by commencing to vitrify them, the absence of

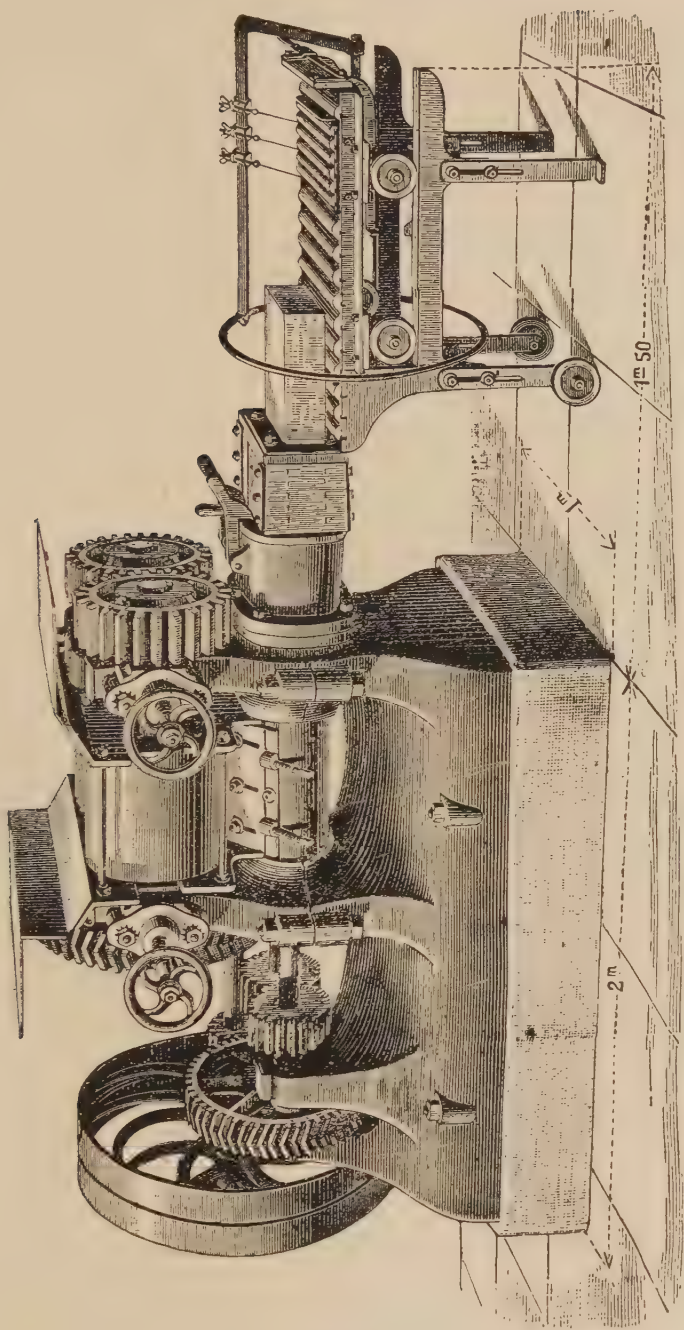



FIG. 197.—Brick Machine.

cohesion in the body. This process is used to join together very sandy materials, pressure partly making up for the lack

of plasticity, or even when, with the object of manufacturing them cheaply, it is desirable to simplify the preparation of the body and to leave out, more or less completely, the drying of them.

The body is nearly always a sandy clay, unmixed, that is simply reduced to a homogeneous powder, and is given as much dampness as corresponds to the pressure that can be dispensed with. This can be prepared from hand to hand in its course, by cutting up the clay by means of a scraper, or by allowing it to break up in the open air, and then moistening

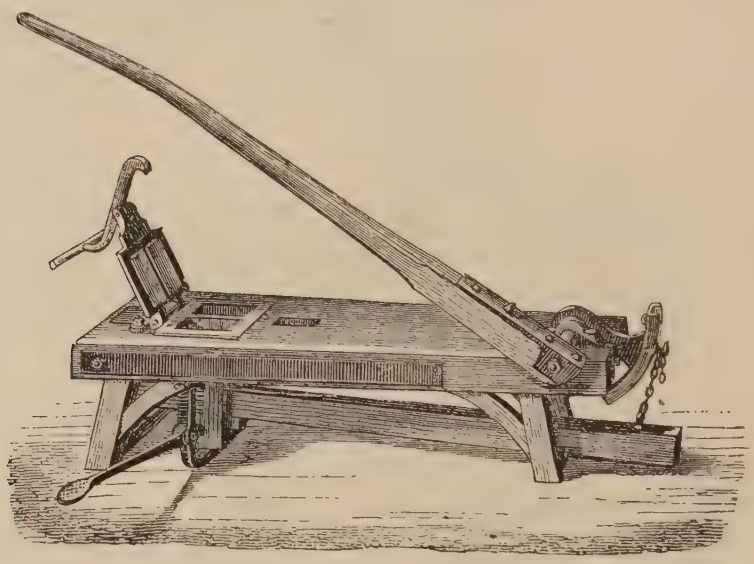


Fig. 198.—Brick Press.

it afterwards. For large quantities, either granulators (Art. 71) are used, or mixers. It is only by being granulated and mixed up together very carefully at first that bricks of a satisfactory quality can be obtained.

There are a very large number of presses on very different systems; a complete description of them would only have a moderate interest, and would overstep the limits of this work, so we will content ourselves by giving some examples of them.

*Moulds* are always by pressure and usually are arranged on one of those methods that have already been described (page 223).

For small quantities, a pressure by shock may be made use of, of which an example has been given (Fig. 105, page 225). Fig. 198 shows a machine of the same kind, which is very much used in small brickfields. The moulds, which are usually of bronze, two in number, have movable bottoms and a cover

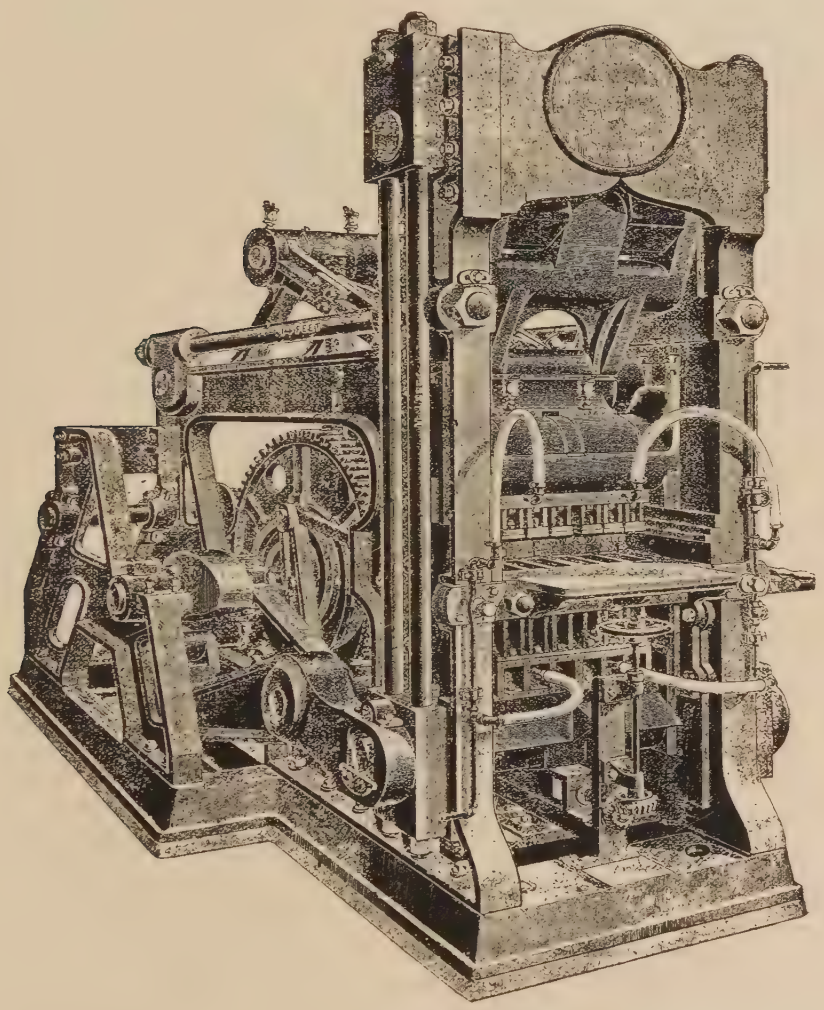


Fig. 199.—Brick Press.

with hinges, which is closed by means of a hook, after the moulds have been filled by hand with the dry body. By using a double lever, a pressure is exerted on the bottom, then the cover is opened, and by means of a pedal the bottom is

raised up so as to help to take the brick out. A moulder with two helpers can thus make about 300 bricks an hour.

For larger quantities and with goods of a better quality, presses with a continuous motion, worked by a motor, are used. The press constructed by MM. Boulet et Cie, which is shown in Fig. 110 (page 230), was a first example of this kind of machine. It can produce 800 to 1,000 bricks an hour, with an expenditure of about 3 horse-power.

The machine shown in Fig. 199 works in a similar way. The six moulds are filled with clay, the upper die is lowered, first rapidly, then, after a very short time of stopping, it gives a second pressure more firmly, after which the bottoms of the moulds are raised in their turn to exert a third pressure. They are taken out of the moulds, as in the preceding presses, by the bottoms being raised quite up. A machine placed in front, acting on one corner, allows the thickness of the brick and

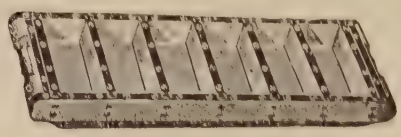


Fig. 200.—Brick Moulds.

the pressure to be regulated. Lastly, the moulds and dies are heated by steam pipes to prevent them from sticking.

Hydraulic presses, the working of which would be the same as that of the eccentric ones, or of those with cams, are not used for making plain bricks, because of their small output.

By using damper bodies, less powerful machines can be employed with good result, but are only suitable for very common goods. The following are two examples of this kind of press, very much used in the United States.

Six wooden moulds joined together, strengthened by iron facings, are used, similar to those shown in Fig. 200. They are placed under the press, which fills them, compresses the body and pushes them on to a board from which they are taken off, while a new group of moulds is put in their place.

Generally, these presses are used with the machines for working up the clay that granulates and forming it into a homo-

geneous mass. Fig. 201 represents a machine of this kind, roughly constructed, with a vertical working-up machine, while in Fig. 202 the press has a horizontal one. The output of these presses is from 2,500 to 3,000 bricks an hour.

We see that in all the preceding machines the shape of the

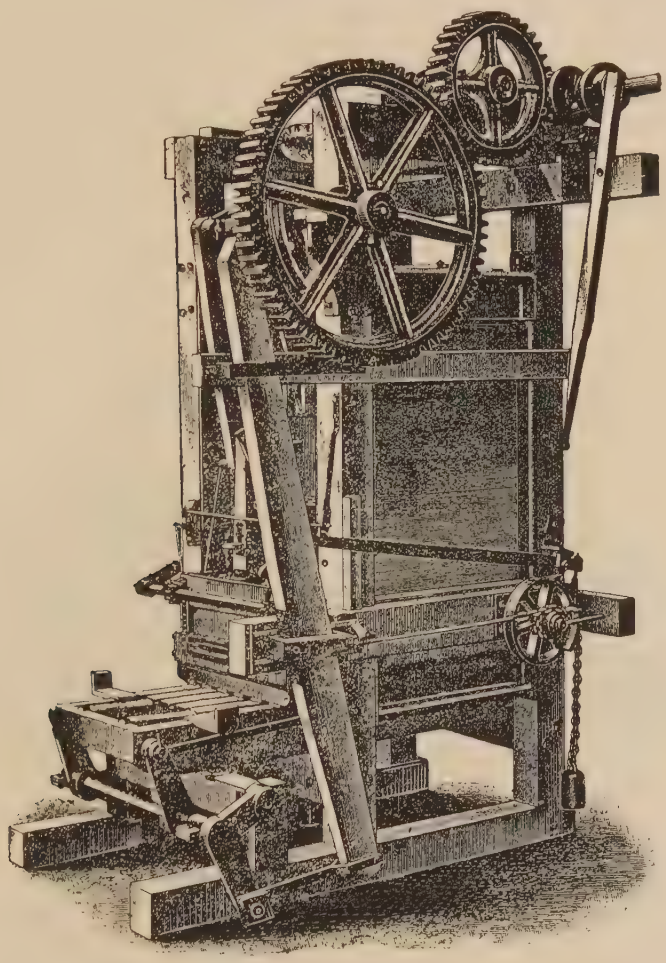


Fig. 201.—Brick Press.

moulds is the same, and the pressure is always exerted by the plunger and also by the bottom. This arrangement is not, however, obligatory, and some presses are differently constructed. It is impossible to describe all the types that have been suggested. We will confine ourselves to the mention of the press shown in Fig. 203, which is known by the name of the Leviathan.

The clay is put into a vertical pug with two driving shafts, which push the clay into four moulds, sunk into four vertical discs which each carry four moulds, making sixteen in all. These discs make a quarter turn each time, and then stop. In the first position they are filled with the body; in the second, which is not shown in the figure, the body is compressed at the same time by the die and the bottom; in the third the bottom takes them out of the mould, the bricks falling on to a circular disc; lastly, in the fourth position, represented in the front of the drawing, they are automatically lubricated by oil thrown on them by a little pump. The yield of this machine is 4,000 bricks an hour.

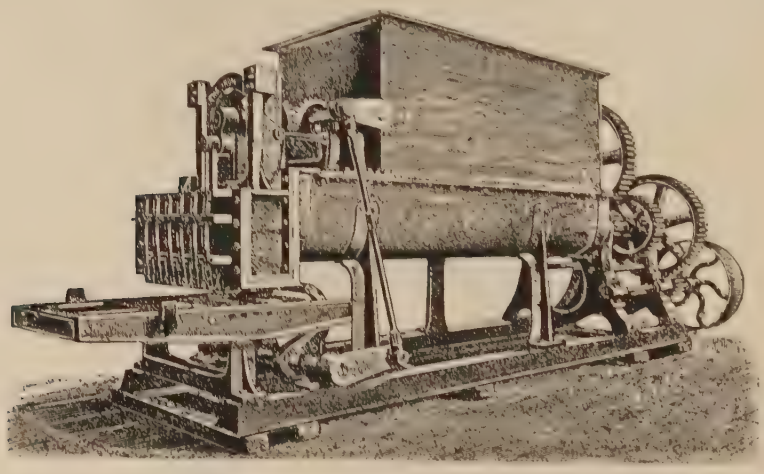


Fig. 202.—Brick Press.

**204. Repressing.**—Bricks can also be manufactured in two separate operations. In the first the bricks are fashioned of plastic body by one of the methods already described; then, when they have been dried and are of a leathery consistency (firm body), they are pressed in such a way as usually to give them a parallelopipedal form, with hollows of a truncated pyramidal form on the two large faces. The object of these is to force the body to push towards the edges when pressed, and to diminish the thickness of the joints by leaving a place for the mortar.

In some cases the object may be to give a perfect form to

the goods, which it would not be possible to do precisely when made rough in soft body.

Before mechanical methods were used, sometimes the dried bricks were struck with flat wooden beaters, to regulate the shape and harden the surface. This process is no longer used for bricks.

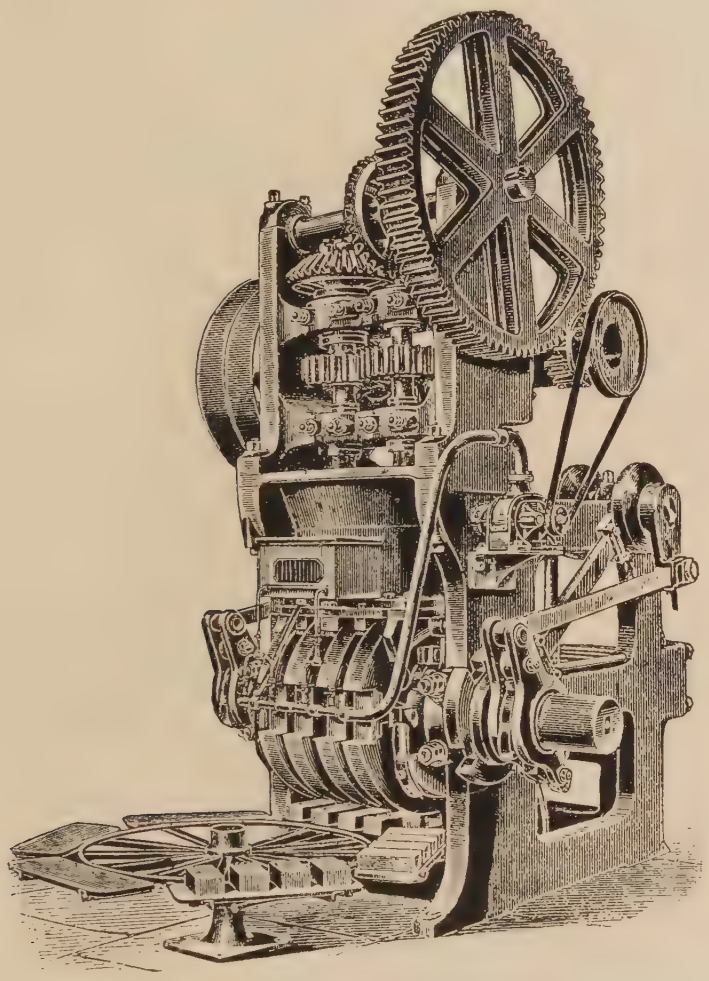


Fig. 203.—Brick Press.

As for presses, so also in repressing, only moulds for pressing are used, and these may work either by a stroke or by pressure. Generally the repress machines worked by hand have a stroke; they are movable in such a way as to be able to be put down in the drying ground and thus avoid the

bricks being carried. Fig. 204 shows the most usual type of repress machine. The brick is placed on the bottom of the mould by a helper, then the workman, standing on the platform shown in the front of the plate, seizes the lever and

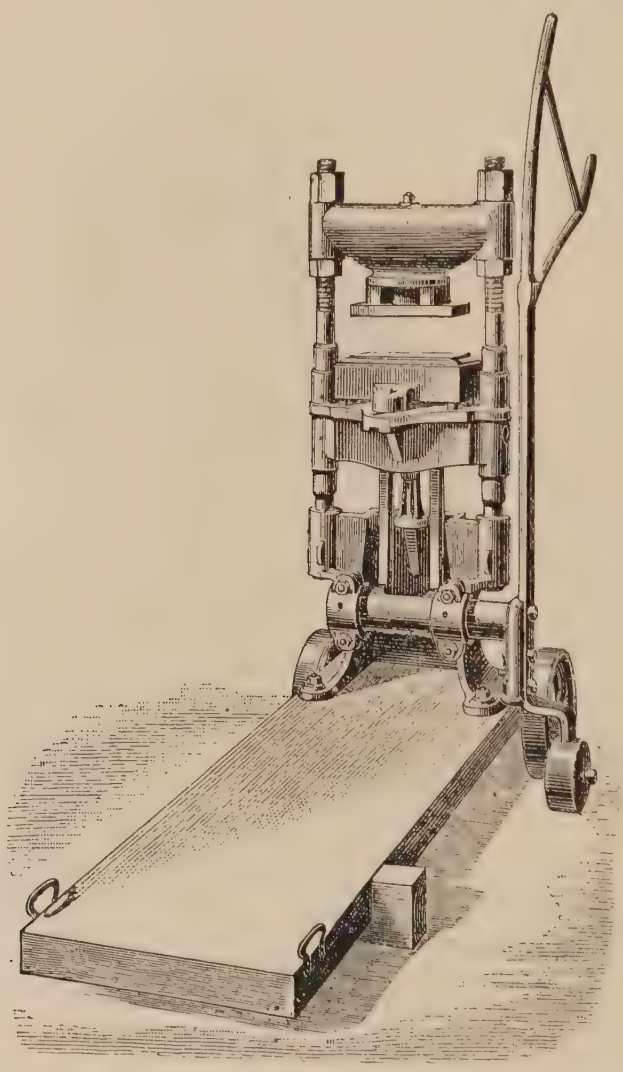


Fig. 204.—Repressing Machine.

throws it violently down, leaning on it in such a way as to make it bear the weight of his body. By this movement the bottom of the mould is lowered, the brick is put into the mould, then the upper chuck, which is larger than the bottom, comes and presses on the brick. The workman makes use of

the elasticity of the mechanism, which tends to raise the lever again after the stroke, and seizes it and replaces it in its original position, at the same time taking the brick out of the mould; the brick is carried away by the labourer and replaced by another one. The platform on which the workman stands is made for the purpose of giving the apparatus more stability. In this way 350 to 400 bricks an hour can be repressed. Sometimes two or three pressings are given in succession, which naturally lessens the output.

We must remark that if the goods, when they are of a suit-

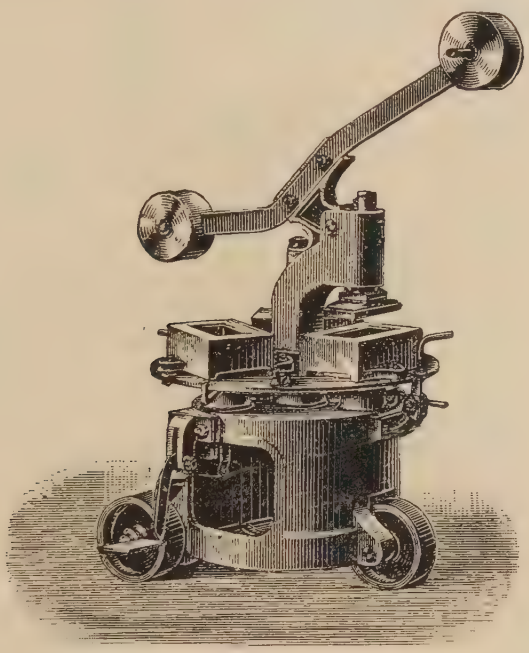


Fig. 205.—Repressing Machine.

able consistency for repressing, no longer present any plasticity for pressing by hand, they yet acquire some under the influence of the much greater pressure by machine, and that they would stick to the walls if the latter were not carefully lubricated. This lubrication is done with vegetable or mineral oils diluted with water, or else with an emulsion of soap.

When the pastes contain lime, the greasy bodies have the disadvantage of becoming saponified in contact with them, thus forming calcareous salts, which are destroyed in burning, but which leave a residue of lime on the surfaces, and this is changed

in the kiln into sulphate of lime and produces whitish blotches that it is impossible to get off. To avoid this inconvenience, which is often very injurious, liquids that do not contain fat acids must be used for lubricating.

A repressing machine of the same kind as the preceding one, but not exerting as much pressure, is shown in Fig. 205. It carries three moulds put on a turn-table, which allows of one being taken out and another being ready for lubricating and putting in the mould. Lastly, Fig. 206 shows a third arrangement, in which the stroke is produced by the great power accumulated in a very heavy fly-wheel. In all these machines the

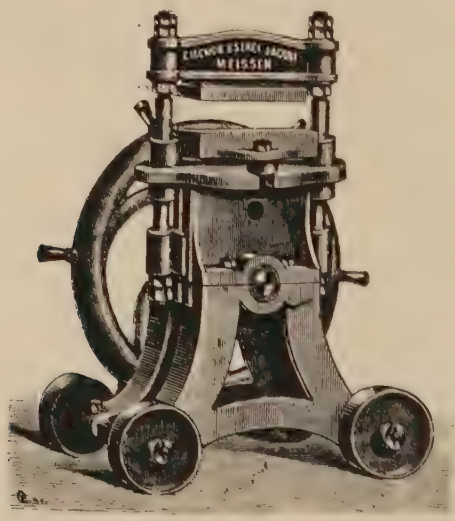



Fig. 206.—Repressing Machine.

driving shaft, on which the lever or the fly-wheel is fixed, carries the tappets or the eccentric wheels that determine the motion of the different organs.

Repressing can also be done in machines driven by an engine, which then work continuously.

The larger output of these machines, which are necessarily fixed ones, does not often make up for the increased expense caused by carrying the bricks. The types of repressing machines of this kind are fairly numerous; the following are only described as examples.

The repressing machine (Fig. 207) constructed by M. Clay-

ton is very much like the types just described. Two eccentric wheels mounted on the motive driving shaft serve to work the bottom of the mould and the upper chuck. On the other hand, the machine (Fig. 208) by M. Pinette is arranged horizontally. The bricks are put on to a travelling slide, placed before the machine, which carries them opposite the mould, where a chuck pushes them in and exerts the pressure. This done, the bottom

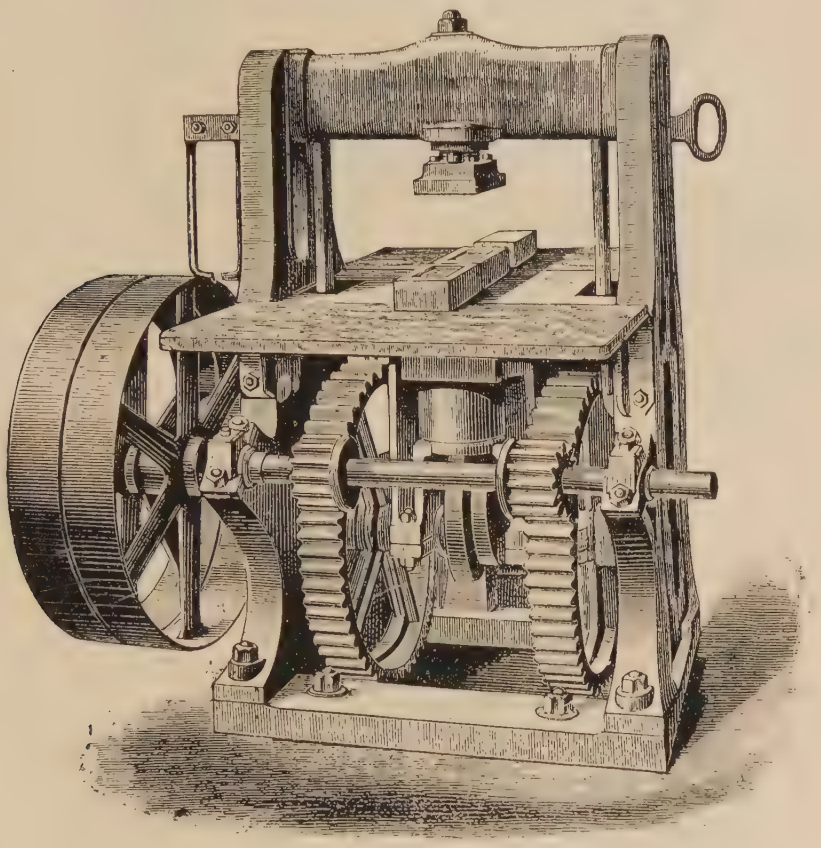


Fig. 207.—Repressing Machine.

of the mould is pushed up in its turn, and puts the repressed brick back on the slide, which, while passing away to put on a second brick, carries the finished brick on the other side, whence it is removed. This machine can repress 1,000 bricks an hour. Lastly, Fig. 209 shows a repressing machine, constructed by M. Frey, in which the bricks are placed on an endless cloth, which carries them into the machine, where they are laterally pressed by a cam, then come out on the other side on

to the same endless cloth. Two rollers automatically lubricate the bricks when they enter. The output is a little larger than that of the preceding machine.

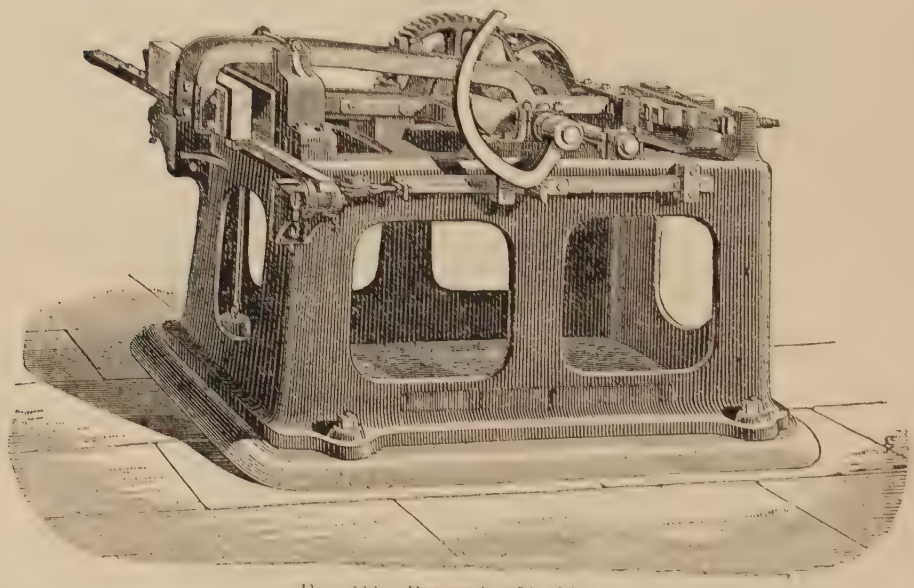


Fig. 208.—Repressing Machine.

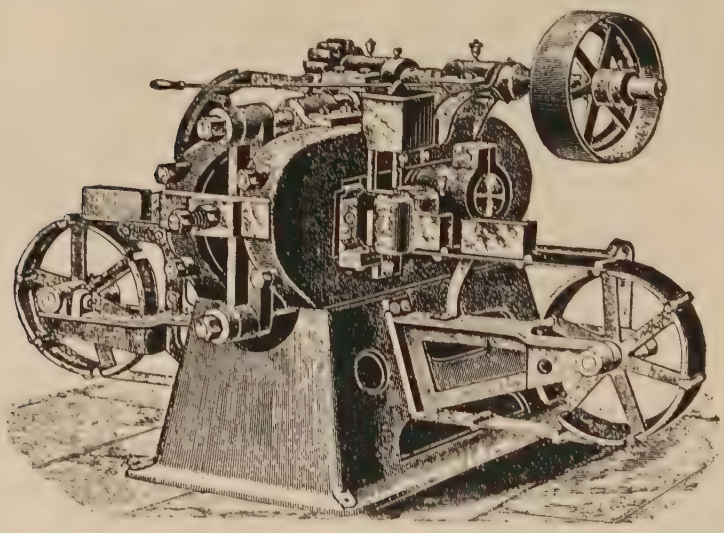


Fig. 209.—Repressing Machine.

To finish what refers to repressing, we will remark that this operation only improves the look of the bricks and not the quality of them. Under the influence of pressure, the molecules

of the body are put out of place and to a certain extent pressed together; but as the plasticity of them is very weak, they blend very badly together, and cracks are left in the goods, as well as smooth parts, which lessen the resistance to breaking.

**205. Drying.**—Drying bricks is rather a difficult operation, on account of the large quantity of water that has to be evaporated. Let us take for example the bricks of the shape most used in France, weighing when burnt about 5·5 lb.; when moulded they contain about 25 per cent. of water if made by hand; or 15 to 20 per cent. when the process of drawing out is employed. When moulded of dry body, this proportion is still further lowered to 5 or 10 per cent. If we reckon on an amount of water equal

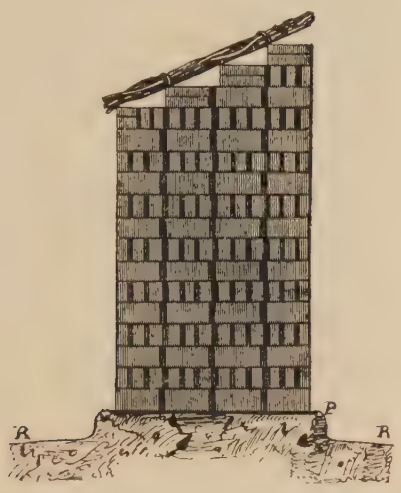



Fig. 210.—Drying Bricks.

to 20 per cent., we see that 17·28 oz. of water per brick must be evaporated, or 1102·3 lb. per thousand.

The drying is done by four processes:—

1. Drying in the open air;

2. Drying on stages which are either isolated, or grouped together in a building;

3. Drying in ventilated drying sheds, using the waste heat of the kilns;

4. Drying in warmed and ventilated drying sheds.

*Drying in the open air* is only used when they are moulded by hand. Over large surfaces of hardened ground, slightly sloping so that the water does not remain there, the bricks are

placed, when they come out of the mould, flat down side by side. When they have hardened sufficiently, they are spread out; then, after drying again for a time, they are piled up into a heap—in *gambets*, according to the technical term. These *gambets* are placed on the higher parts of the ground, the lower row often being of burnt bricks, to avoid damp. When there is any fear of rain the *gambets* are covered over with straw matting, planks, or other light movable coverings. Sometimes one side of them is covered as well, to prevent the rain being blown on them by the wind. In these *gambets* the bricks finish drying.

*Drying on stages* is done either in little separate sheds, or in sheds that contain several rows of stages, or even in build-

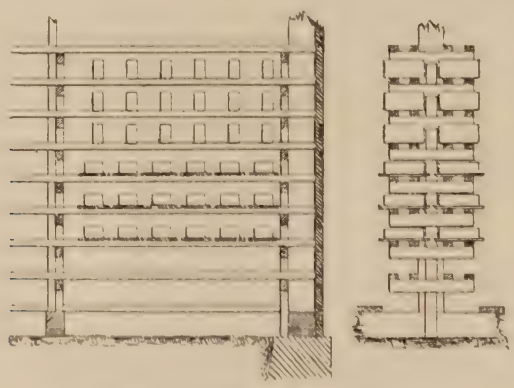


Fig. 211.—Drying Bricks.

ings usually constructed over the kilns. Figs. 118, 119 and 121 showed the different arrangements in general use. There is therefore no need to repeat them.

When they are made of soft body, the bricks ought to be put on little boards, and put down flat. If, on the contrary, the body is partly hardened, or dry, they are at once placed on two strips fixed to the uprights of the stages. Fig. 211 shows these two arrangements.

Bricks are sometimes put, directly they are made, on boards about 4 feet to 5 feet long, which are carried to the stages, where they take the place of the strips in Fig. 211. Lastly, in some cases, movable stages, or, at least, those that are partially so, are used; these are formed of planks that have at their

extremities the ends of the planks, so that they can be piled up as shown in Fig. 212.

Carrying the bricks to the drying sheds, and from the drying sheds to the kiln, is somewhat important, on account of the great weight of the goods to be moved about. For this purpose different methods are employed, which depend upon the arrangements of the drying sheds.

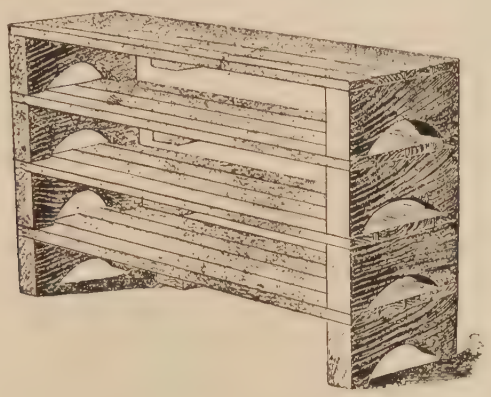


Fig. 212.— Pallettes for Drying Bricks.

Wheelbarrows are very much used, because they can easily be moved about between the rows of the stages. Those that are used for carrying green bricks are flat in form, as shown

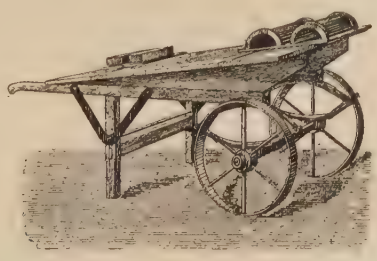


Fig. 213.—Wheelbarrow.

in Fig. 213. It is wise, so that the shaking of the rolling along should not spoil the shape of the goods, to suspend them by means of springs, or to use india-rubber bands. For transporting dry bricks, simple flat wheelbarrows, with backs, are used. When it is necessary to raise the bricks on to the stages, the wheelbarrows can be pushed up inclined planes, or they can be raised by a lift.

Little waggons are less used, because they need a considerable amount of railway to be made if they are to be carried along between the stages. For green bricks the waggons shown in Fig. 214 are used, and for dry bricks waggons of the usual flat shape. In some cases waggons suspended from an overhead railway have been used. This method, when the arrangements permit of it, may be more practicable than the preceding one.

When the making is done in a building in floors which contains the drying sheds, elevators can be arranged by the side of the machines, and the bricks, being at once placed in them, can then be taken to the different floors, to be put on

Fig. 214.—A Little Waggon.

wheelbarrows and spread on the stages. Fig. 215 represents an elevator of this kind, to which the desired height naturally can be given. It is composed of two double pulleys, on which turns a chain carrying boards used for receiving the goods, and which are suspended in such a way as to remain horizontal while being raised.

The length of time needed for the drying on the stages depends on the arrangements of them and on the weather. We have already said that the drying was, at a height of 10 feet, double that on the ground itself, and triple at the height of 20 feet. On the ground it varies according to the weather from two to five weeks in favourable seasons. It can be re-

duced, when the stages are raised and under better conditions, to ten, or even eight days.

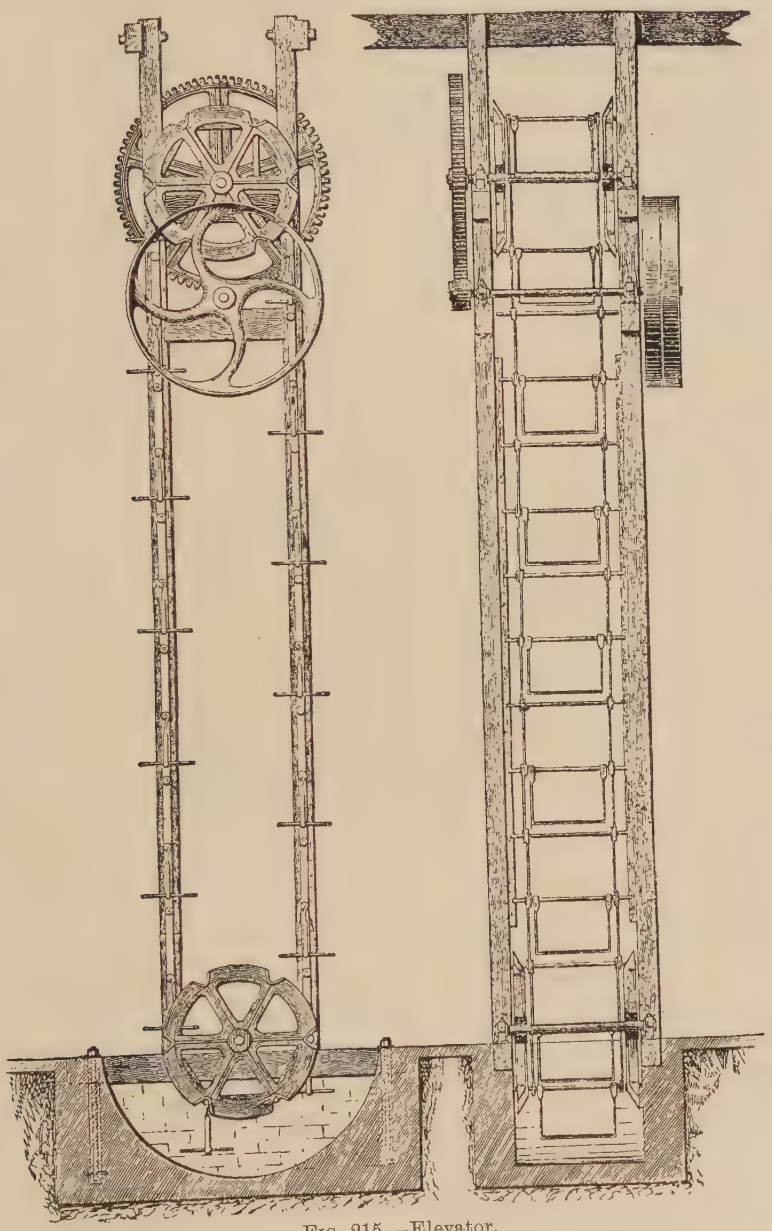


Fig. 215.—Elevator.

By arranging the drying sheds over the kilns, as shown in Fig. 121, they can be dried at any season if the building is well closed and the weather not too severe. The length of drying,

nevertheless, depends largely on the season, even with the best arrangements. It is double, or even triple, in winter to what it is in summer.

The drying can be noticeably improved by arranging ventilators in suitable places, which can be made to act in calm weather, when the natural draught becomes insufficient or there is none at all.

*Ventilated drying sheds, using the waste heat from the kilns* can also be used. Fig. 122 (page 260) shows an arrangement of this description. The kilns are always those with continuous firing, and the ventilation is done by chimneys or ventilators. Several arrangements have been proposed by Messrs. Ohle (the one in Fig. 122), Cohr, Rühne, Hoffmann, etc., but they do not seem to be any better than drying by ventilation in a building over the kilns, especially when an insufficient draught can be supplemented by ventilation.

It has been seen, in fact, that the heat necessary for evaporating 1 kilogramme of water contained in the body is given in formula III. (page 251):—

$$C = \frac{1{,}000\,(T - \theta)\,c}{E\,(T - t)},$$

with the condition II.:—

$$E\,(T - t) \leqq P - p.$$

If it is admitted that the outside temperature is equal to 0, that $T = 20°$, it will be seen that the heat expended is at the lowest for $t = 11°$, in which case $C = 1{,}360$ calories (p. 256). We have seen that this number must be increased from 50 to 100 per cent., according to the installation, and becomes, under the most favourable conditions, equal to 2,000 calories.

If, on the other hand, we agree as to a body having 10 per cent. of water to be evaporated, 1 kilogramme of burnt brick will contain 150 grammes, thus needing 300 calories. But, as we shall see in the following article, the quantity of heat that a continuous kiln can furnish while burning bricks, theoretically will scarcely expend more than 200 calories per kilogramme of the burnt body.

It can then be laid down, as an absolute fact, that it is impossible to dry bricks solely by the waste heat of continuous

kilns, the only heat available in brickfields when worked economically.

It is this fact that has caused *heated and ventilated drying* sheds to be used sometimes, the different systems for which were shown in Figs. 125, 126, 127, 128, 129 and 130. When the stages are fixed, the bricks are placed as already described. When they are movable, waggons of a flat pattern are used, which carry fixed stages, or, better still, movable iron supports as shown in Fig. 216. It is these waggons loaded with bricks that have been introduced into the drying sheds.

There are several different kinds of these drying sheds, and the three following engravings are only given as examples.

Figure 217 shows a drying shed built by Messrs. Chamber

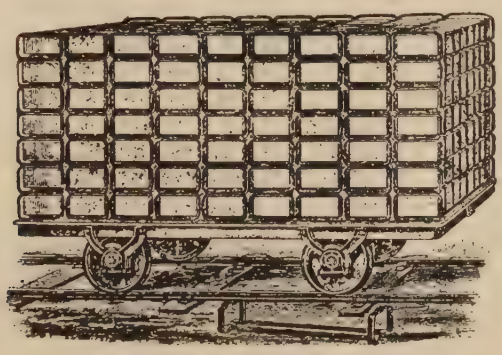


Fig. 216.—Waggon for Drying Sheds.

Brothers & Co. It is of type C (p. 263, Fig. 126), in which the bricks are not moved while being dried, and is composed of a series of separate tunnels, heated at one end and furnished with a draught chimney at the other.

Figure 218 shows a drying shed of type B (p. 483), in which the goods are moved about in the same direction as the air, the latter being heated progressively by a subterranean system of pipes containing steam. It was constructed by Messrs. Wolff & Co.

Lastly, Fig. 219 represents M. Moeller's drying shed, the plan of arrangement for which was given in Fig. 130 (p. 268).

In order to calculate the dimensions for drying sheds and the number of waggons, the length of the drying must be

reckoned, which depends on the nature of the body, on the method of manufacture, and the arrangement of the drying shed. Under the most favourable conditions this time can be reduced to 20 or 24 hours, but it is often very much longer.

What was said in Chapter V. allows of the value being compared and of the consumption of fuel being estimated for the different drying sheds. It is sufficient to add that heated drying sheds, even when the bricks are manufactured of dry bodies, are more suitable for countries with a cold or damp climate. It seems hardly likely, under the present conditions of the brick industry, that it would be advantageous to use these processes

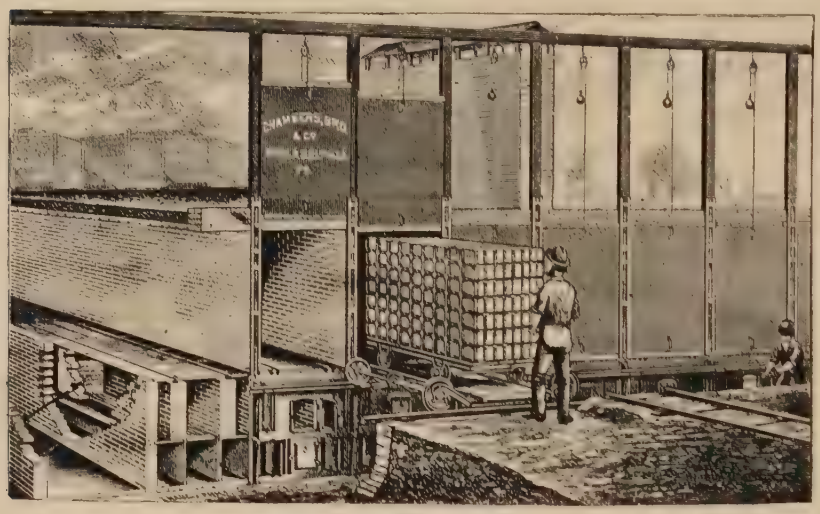
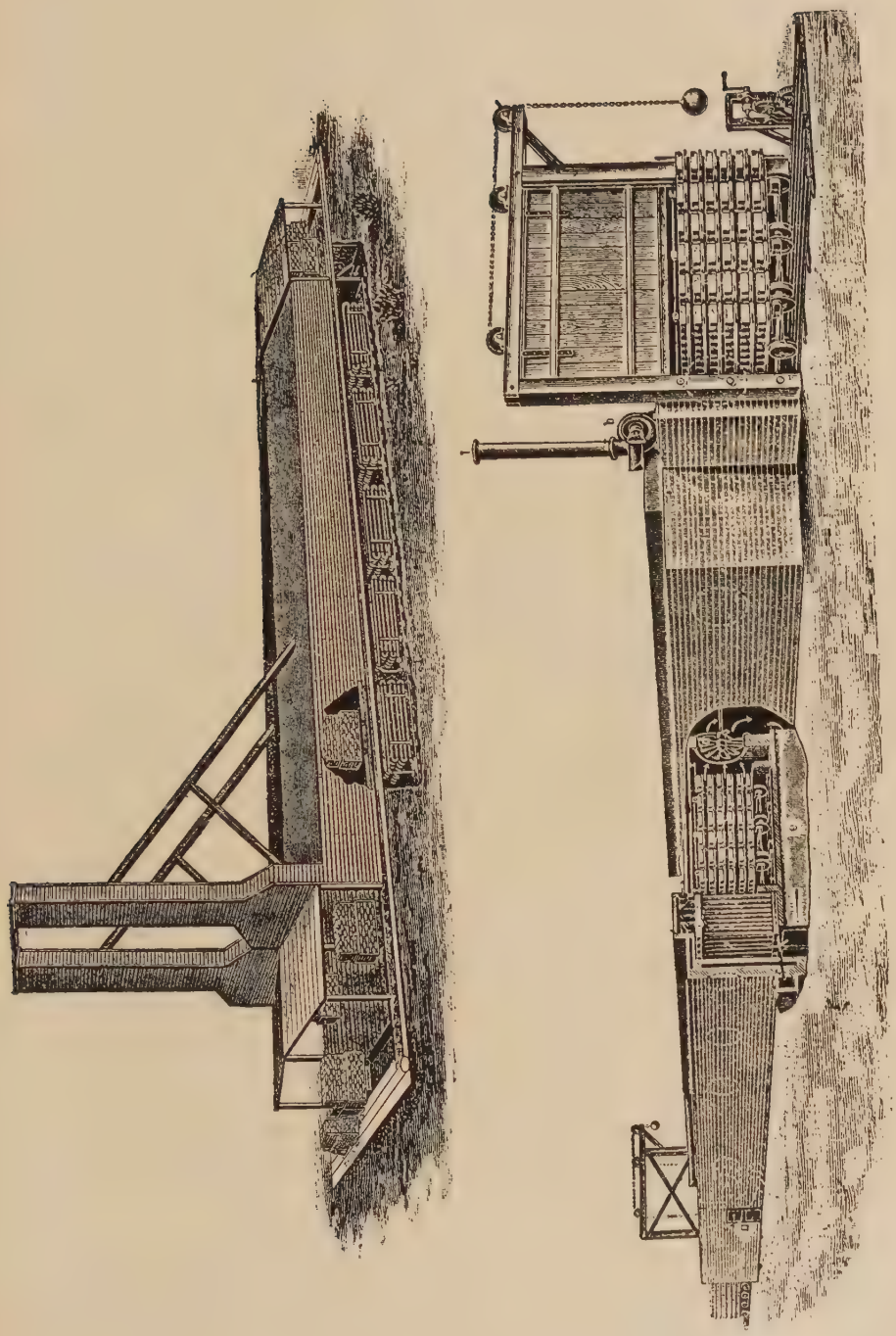


Fig. 217.—Drying Shed for Bricks.

everywhere where, as is usual in France, they can be dried in winter on stages suitably arranged above the furnaces.

**206. Burning.**—The burning of ordinary plain bricks is sometimes done *open*. This process usually accompanies moulding by hand, and as it needs special workmen, we need only make some general remarks about it.

The site for the kiln ought to be a piece of ground placed away from water and close to the brick stages. They begin by putting down a first layer of burnt bricks as a foundation, as shown in Fig. 220, in such a way as to make a square measuring 11 to 16 yards a side. On this is put a second layer, the burnt bricks being placed perpendicularly to the first ones, and also separately.



FIGS. 218 and 219.—Drying Sheds for Bricks.

The third layer is also made of bricks laid down edgewise, but arranged in such a way as to leave only a space of $\frac{3}{4}$ to $1\frac{1}{8}$ inch between them. Having reached this height, the channels that cross the kiln are filled with wood and shavings, then the fourth layer is put on, composed of two courses of bricks flat down, separated from one another as in the preceding case. At the fifth layer the channels are covered over with flat bricks, the others being placed edgewise at intervals like those already mentioned. The sixth layer is put perpendicularly to the fifth, then the seventh like the fifth, the eighth like the sixth, and so on. The bricks at the edges are closer together, put more carefully, and placed in such a way as to give a slight roughness to the faces, which are covered over with a layer of sandy clay.

Between the sixth and seventh layer is powdered over a thin layer of sandy charcoal, spread evenly about, and the same is done every three layers. The first seven or nine layers are of burnt bricks, as they form the *foot* of the kiln, the others are raw. When the foot is finished, which will take a gang of ten to fifteen men a whole day, in the evening the wood put in the channels is lighted, and the fire is fed with faggots, blocks of wood and coal. The next day the charging is continued so as to put on three or four layers.

When the fire has well caught the first layer of coal, which can be told by the smoke, which ought to come evenly out of the whole surface of the charge, the speed of the combustion is regulated by lessening the size of the openings which let the air in. Each day the charging ought to follow the progress of the combustion, which has a tendency to become quicker, so that towards the end of the burning as many as four to six layers are put on. They usually stop when the kiln is about 8 yards high, and the last layer is put on closer together than the others.

With such a primitive method of burning it is natural that accidents should be frequent. If the fire is not spread evenly over, the entrance for the air is lessened on the side where it is too quick, and any *chimneys* that may occur are stopped up from above by putting fuel into them. In the same way the fire

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is quickened in the parts where it is too slow, by unstopping the air entrances. As the centre is necessarily more burnt than the edges, it sinks more into a hollow, and the difference in level is put right by placing a layer in which the bricks are edgewise in the centre, and sloping or flat down at the edges. But the most serious accident that can happen is the rain, from which it is difficult to protect the kiln, even with movable coverings. Therefore the burning in the open can only be done in the summer.

The kilns contain from 200,000 to 1,000,000 bricks. Those

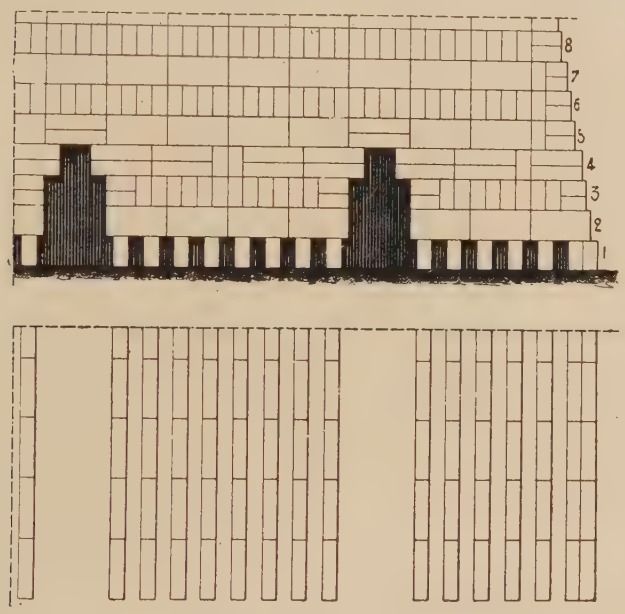


Fig. 220.—Burning in the Open.

most used are for 500,000, of which about a sixth are waste or too little burnt. The consumption of fuel varies from 63·5 lb. to 81·6 lb. of coal per 1,000 bricks, according to the quality of the coal and the size of the kiln. Turf has sometimes been made use of.

Burning in the open is used in the north of France, in Belgium and in England. It can only be used when the body is sandy and is of no use except in small temporary brickfields, formed near to and in view of a particular building.

For small fields in the colonies, *intermittent kilns with ascending flames* can be used, of the type shown in Fig. 158 (page 354), the heating being either with coal, wood, grass, straw or any other fuel.

Besides the two special methods which have just been described, bricks ought to be burnt in continuous kilns with one gallery; it is only in very small brickfields, created for local needs, that use is made of semi-continuous kilns.

The kilns with continuous firing have already been described (page 363), and we have seen that instead of their primitive round form, later an oblong one, there has been substituted at the present time a rectangular form (Fig. 168).

Figure 221 represents a kiln of this kind, with more of the details of construction, specially intended for burning ordinary bricks. Each of the two parallel galleries is divided into six, seven or eight compartments, each having a door for charging, a draught valve and an arch making a projection in the walls of the burning gallery, against which the dampers are arranged. These dampers were formerly of iron plates in two or three pieces, to allow of their being put through the doors. Now they are made of paper, luting them with earth mortar against the arch. When they need to be removed, the lower part of them is simply torn away, so as to allow the gaseous current to pass, the pieces of paper naturally being destroyed during the burning.

The openings in the dome, by the side of each archway, are intended specially for this operation.

The paper that is used is bought in rolls about 40 to 56 inches wide; it is cut and pasted in such a way as to prepare a piece of the identical shape of the opening from the gallery for burning.

The heating is done with coal, lignite or turf, the fuel being put in through a series of openings formed in the dome, about 40 inches apart, and closed by cast-iron covers. The charging is arranged as shown in Fig. 143 (page 333).

The following are some data as to the production and dimensions of these kilns:—

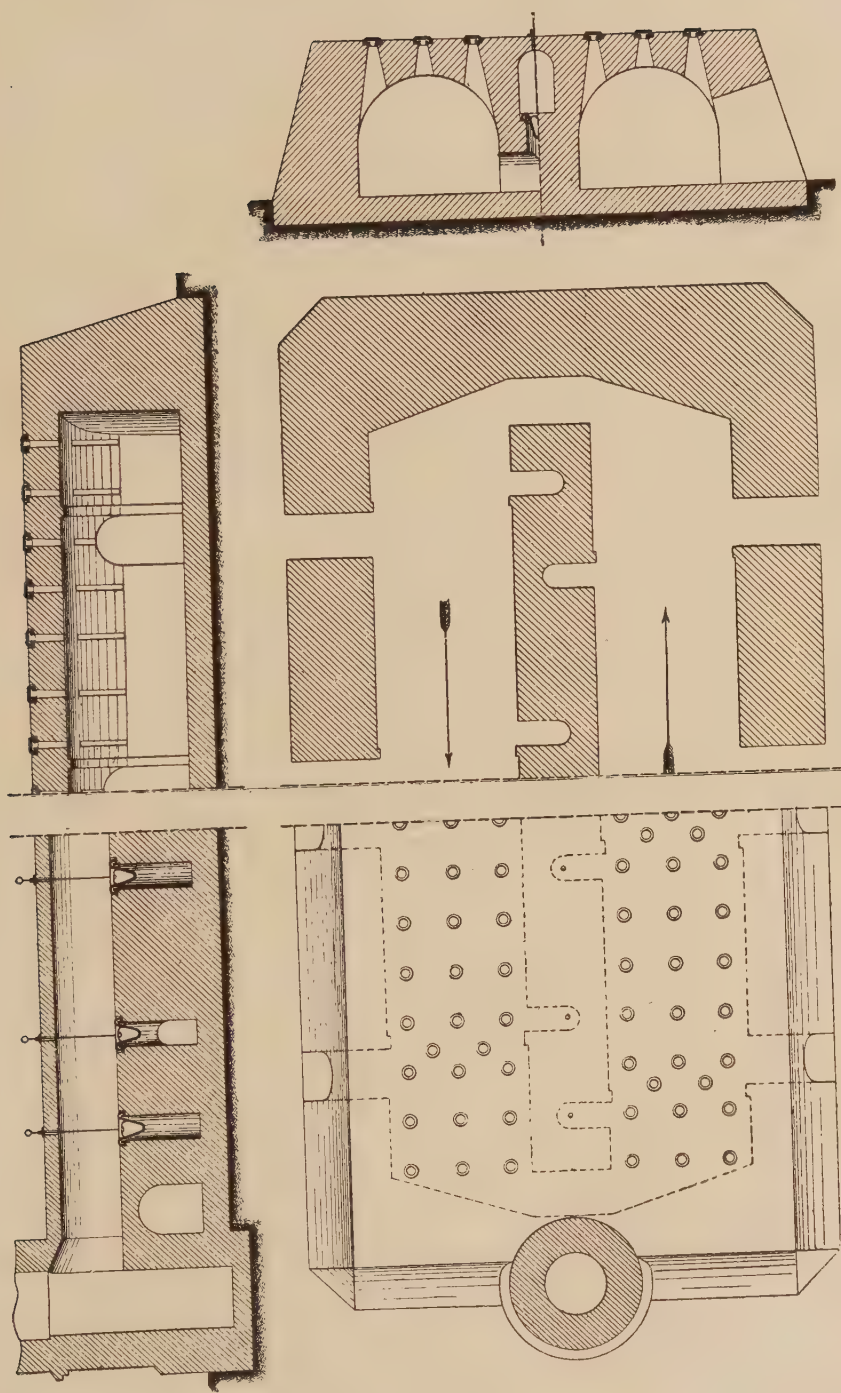

Fig. 221.—Kiln with Continuous Firing, for Solid Fuel.

| Volume of a Compartment. | Number of bricks $8\frac{1}{2} \times 4\frac{1}{4} \times 2\frac{1}{2}$ in. burnt in 24 hours. | Dimensions of the Kiln. | |
|---|---|---|---|
| | | Length. | Breadth. |
| Cubic Feet. | | Feet. | Metres. |
| 352 | 4,000 | 65 to 82 | 6 to 7 |
| 528 | 6,000 | ,, | 7 ,, 8 |
| 704 | 8,000 | 82 to 115 | 8 ,, 9 |
| 880 | 10,000 | ,, | 9 ,, 10 |
| 1,058 | 12,000 | ,, | 10 ,, 11 |
| 1,408 | 16,000 | 115 to 148 | 11 ,, 12 |
| 1,760 | 20,000 | ,, | 12 ,, 13 |
| 2,116 | 24,000 | ,, | 13 ,, 14 |

With a normal working the fire advances one compartment, that is from 10 to 21 ft., in twenty-four hours. Naturally this amount can be diminished or turned into a compartment and a half. For a yield above 25,000 to 30,000 bricks it is better to employ two distinct kilns.

The type of kiln shown in Fig. 221 can be varied in several ways. A few words on the principles of them will suffice:—

1. The chimney joined to the end of a kiln can be put quite away from it, either at the end or at the side (Fig. 168). From the point of view of the draught, the position shown in Fig. 221 is the best.

2. The flues for letting off the gases, instead of being placed laterally in the central wall, can be arranged on the outer wall, or go under the hearth. These arrangements, which seem theoretically more logical in practice, are not of any advantage in spreading the heat well about, and have the disadvantage of being more complicated in construction.

3. The gases can also be carried off through the openings for heating by making the latter communicate with the smoke channel by means of movable sheet-iron pipes, which are displaced as soon as the fire advances.

Figure 222 shows the arrangement in section (Siehmon & Rost).

It is of rather more simple construction, and when the goods are very damp lets off the steam better which, on account of its smaller density, is apt to accumulate under the dome. On the other hand, the moving of the pipes is a much longer operation than the simple raising of a valve. Also, it must be

stated that it is preferable to make the draught by the special lower channels, and when the raw goods are too damp, as is sometimes the case during bad seasons, the carrying off of the steam may be assisted by means of upper pipes.

4. The warming of the bricks that are freshly charged sometimes needs special arrangements. What has just been described is nearly always sufficient, but when the bodies are very damp, too plastic, or very calcareous, other methods must be tried. Sometimes little movable fireplaces, heated with coke, and with the flames thrown back into the heating shafts of the compartment that is being warmed, are arranged for, care being taken to allow rather a large quantity of air to enter at a low temperature, rather than a small quantity of very hot air. These fireplaces can also be put in the doorways or be fixed into the outside wall. In some cases, fortunately very

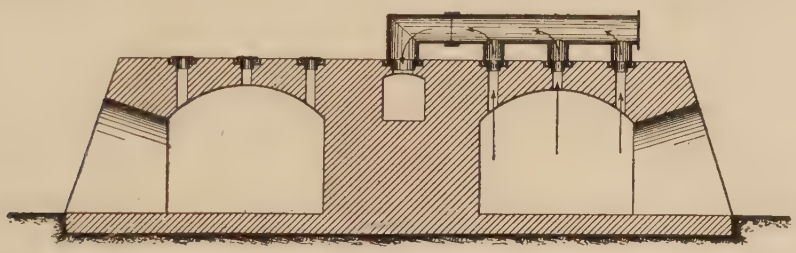

Fig. 222.—Brick Kiln.

rarely, the heating is obliged to be finished by fixed fireplaces by means of a system of pipes under the bottom of the kiln. It has also been proposed (Hoffmann) to take the warm air from the compartments that are cooling down, and to carry it through a special system of channels into the compartment that is starting, but this method does not answer well.

5. For temporary establishments that only need to last one, two, or three years, the construction of the kiln can be simplified by putting part of it in the ground, and replacing the greatest part of the masonry by embankments of earth, as shown in Fig. 223. Thanks to the low price for this construction, burning in this kiln is cheaper, including the money sunk, than in kilns in the open air, when the total number of bricks to be made is above 2,000,000.

6. It has been said that the kiln shown in Fig. 221 was

intended for heating with small coal, lignite or peat. Blocks of wood can also be used in it; but for heating with small wood, faggots, straw, etc., the kiln with trenches shown in Fig. 171 (page 369) must be adopted.

The consumption of fuel is from 77 to 110 lb. of medium quality coal per ton of burnt bricks, according to the height of the temperature and the nature of the body.

The thermic yield of continuous kilns for burning bricks can be reckoned as follows:—

| | | | |
|---|---|---|---|
| Heat produced by the combustion | 100 | Heat that is theoretically of use . | 90 |
| Heat furnished by being collected | 40 | Heat lost by heating the walls . | 20 |
| | | Heat lost by radiation . . . | 25 |
| | | Heat lost by the chimney . . | 5 |
| | 140 | | 140 |

The air used is, in a medium way, $1\frac{1}{2}$ time that which is theoretically necessary. If this proportion were increased, a

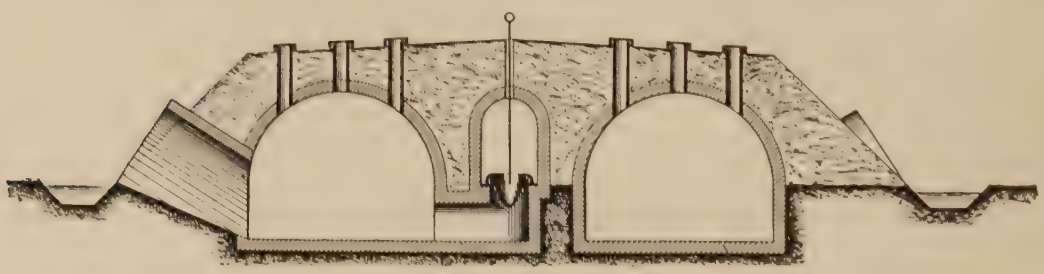

Fig. 223.—Temporary Brick Kiln.

larger proportion of caloric could be recovered, and consequently the consumption of fuel could be lessened. In order to have a complete recovery of it, it would be necessary to employ from $2\frac{1}{2}$ to $3\frac{1}{2}$ times as much air as the theoretical proportion. But then the temperature would be lowered to a considerable extent, and it is the consideration of this that limits the amount of draught. Practically, a double volume of air must not be exceeded for the lowest temperatures, and it ought to be reduced to $1\frac{1}{2}$, as we have put down in the preceding calculation, for medium temperatures.

**207. General Arrangements of Brickfields.**—Brickfields are essentially local factories, because of the great number of deposits of clay suitable for making bricks that are met with in all countries, and also of the great weight of the goods in

comparison to their value. The cost price of making bricks varies, except in extraordinary cases, from 3s. 3d. to 6s. 6d. per ton, to which must be added from 20 per cent. to 50 per cent. for general expenses. The reduction in the cost price that can be made by a large output is thus rapidly made up for by the cost of transport. In fact, important brickfields are only found near large centres of consumption.

From the point of view of the processes of manufacture, brickfields can be divided into three classes:—

1. Those using moulding by hand and intermittent kilns.

2. Those using the same method of moulding, but burning in kilns with continuous firing.

3. Those moulding by machine, and naturally making use of continuous kilns.

Besides the two cases which have already been mentioned, the first are justified when the output is below 600,000 or 1,000,000 bricks per annum. That is, in fact, the limit below which it is not economical to use kilns with continuous firing. On the other hand, it may also be admitted, as a rule, that the use of mechanical motive power is only advantageous when more than 10,000 bricks per day are moulded. The brickfields of the first class, then, are small factories, essentially local ones, which can only prosper by being protected from the large makers by the expenses of transport being rather high, and by having the general expenses very much reduced.

It has been shown before that for making very common bricks, with suitable clays and climate, it is better to employ hand moulding, even for large quantities. In this case the places for moulding and drying must be arranged round one or more continuous kilns, so as to reduce as much as possible the carriage of the goods in course of manufacture. The works are placed by the side of the clay pits, the clay being brought by means of waggons. If the consumption of the bricks is not in the same neighbourhood, the factory ought, besides, to be near a railway or a watercourse.

Lastly, in the brickfields of the third class, using machines and continuous kilns, the drying is done either in sheds, or in large buildings above the kilns, or else in artificial drying

sheds. It is impossible, in the present state of this industry, to give, on principle, the preference to any one of these systems. The choice depends on local conditions.

It has been seen that the maximum output of a continuous kiln was from 25,000 to 30,000 bricks in twenty-four hours, which, reckoning for stoppages, holidays, etc., is equal to a production of 30,000 to 40,000 bricks a day. For a larger production two kilns are arranged side by side in two buildings 40 or 50 ft. from one another, the place containing the machines being between the two. This arrangement, which can make from ten to twenty million bricks a year, is the largest that can be employed. Above that, two or more independent works must be made.

In all brickfields, above everything, the cost of transport must be reduced if possible, and all unnecessary handling of the goods must be avoided; it is only on these conditions that a remunerative working can be hoped for.

### (*b*) *Hollow Bricks.*

**208.** We have already seen that the manufacture of hollow bricks as an industry only dates back to 1855. The use of them has considerably developed since then, especially in France. They are principally used for the construction of partitions, light walls, and for filling in the intervals between the girders in floorings.

Figure 224 represents a number of types of these bricks, generally used for partitions; they are from 8·6 to 13·7 inches long, 4·13 to 6·7 inches wide and 1·2 to 4·3 inches thick.

Figure 225 gives examples of flooring bricks. Type I. is used for light floors, and is from 15½ to 22½ inches long, 8 to 9¾ inches wide, and 2 to 2¾ inches thick. When the brick rests on the lower wing of the girders of the floor it is advisable to cut them as shown in the drawing, so as to make a place for the wing. Type II. is meant for solid floors, having a space between the girders of 2·35 to 3·12 inches. The bricks are usually 8·58 to 11·7 inches long by 4·0 to 4·70 inches thick. Lastly, Type III., made of "summer" bricks, with hollow bricks for the

partitions, is used for very strong floors intended to bear great weights.

Besides, hollow bricks can be made in very various forms, intended for the most different uses. So as not to go outside the scope of this work, we will simply say that, in a general way, in order to have a regular and economical working, the following dimensions should not be exceeded: 18 inches long, 10 inches wide, and 6 inches thick.

The bodies used for moulding hollow bricks ought to be more plastic than those for making plain bricks.

The moulding is always done by expression; the dies used

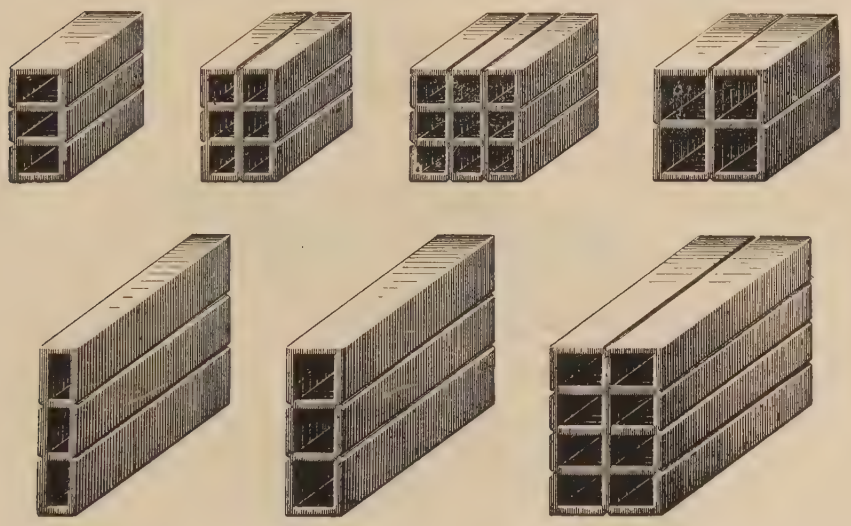

Fig. 224.—Hollow Bricks.

for this purpose have been described in Chapter IV. (page 195). For small goods piston propellers are used (Fig. 75, page 199), and other propellers for a larger manufacture. It is needless to repeat what has been said on the subject of these machines, yet it would be advisable to remark that the propellers with cylinders are especially suitable for large quantities of hollow bricks, and are to be preferred in a general way.

When it is required to mould hollow bricks of larger dimensions than those already mentioned as being the maximum, as, for example, the flooring bricks of Type I. (Fig. 225), a rather stiff body must be used, as then there is less shrinkage. In that case piston propellers can be used. The method used in

this case is the same as that used for the manufacture of the tiles, in cake form, of stiff body, which will be described further on, in Art. 216.

The *drying* of hollow bricks does not present any difficulty. It is much quicker than that of plain bricks, and the goods have much less tendency to get out of shape.

The *setting* of them is also very easy; they are put in close against one another, the spaces of the holes being sufficient to secure the circulation of the gases and flames. Lastly, the *burning* of them is more rapid than that of plain bricks, and it is easier to spread the heat uniformly over the kiln.

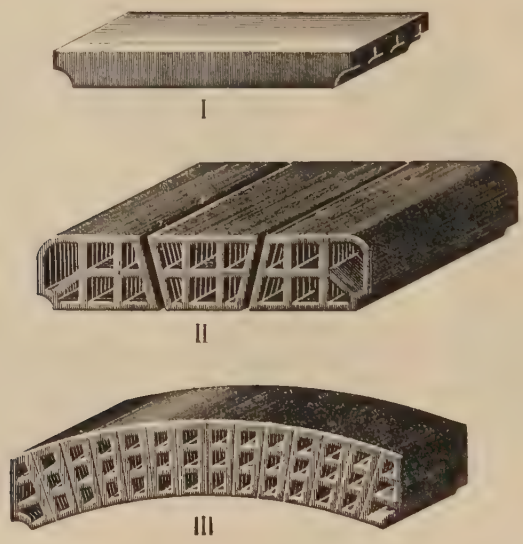


FIG. 225.—Flooring Bricks.

There are scarcely any special factories for hollow bricks, as they are produced either in brickfields, or more usually in tile works.

### (c) *Ornamental Bricks.*

**209.** When the bricks of special buildings are to be exposed, that is to say, are to be neither painted nor covered with stucco, the bricks called ornamental bricks are often made use of. These are distinguished from ordinary bricks by their more regular shape, the uniformity of their colouring and their finer grain, and their greater resistance to the changes of weather. If,

from a potter's point of view, ornamental bricks do not differ from ordinary bricks, nevertheless, in order to obtain the qualities just enumerated, it is necessary to have recourse to a more careful manufacture of them. This extra care needs to be specially mentioned as it affects the industry.

The body ought to be better prepared and more carefully mixed than it usually is for ordinary bricks, and, besides, it is necessary for it to be of a composition calculated to give, after baking, the desired shade. It is needless to return to this subject after what was said on p. 308.

When moulded by hand ornamental bricks are not satisfactory; it is necessary for them to be repressed. The brick to the left in Fig. 226 shows the type of repressed brick that is most used. The dimensions are those of ordinary bricks, the width and thickness however are slightly increased, when we

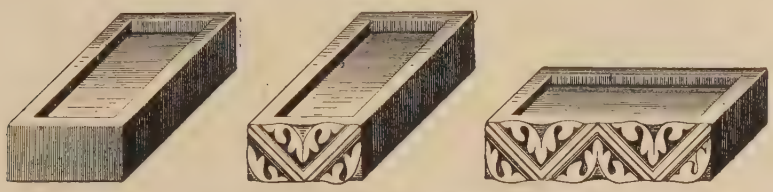

Fig. 226.—Repressed Ornamental Bricks.

remember that the joint of ·4 inch of thickness in ordinary brickwork is reduced to ·23 to ·315 inch for masonry that is to show.

Ornamental bricks can also be obtained by repressing (Fig. 226). For this purpose is arranged, in the ordinary repressing mould, against one of the upright sides, a copper plate with the pattern intended for the brick hollowed on it. The pressure makes the body sink into the hollows of this plate, and the latter is taken out of the mould together with the brick. It is easily taken off afterwards, and replaced in the mould after it has been greased.

When moulded by being pressed out of dry body, the ornamental bricks can be made of regular dimensions, heavy, resisting the inclemency of the weather only when well burnt; but it is costly to make bricks for mouldings by this method.

Moulding by expression is the best and most economical

method of manufacture for ornamental bricks. The surfaces smoothed by the die plates have a regular grain of agreeable appearance, which give a better colour than the joined surfaces of repressed bricks. The drawn bricks are sometimes pressed over

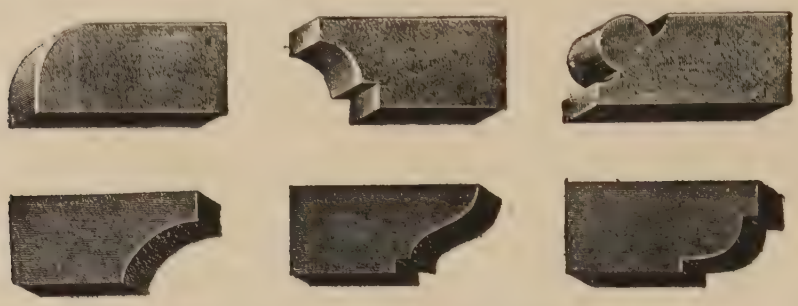

Fig. 227.—Ornamental Bricks, for Mouldings.

again, but this should be condemned, except for ornamented bricks (Fig. 226), because with a little care better goods, from all points of view, can be obtained direct from the die-plate. The cutting of the ornamental bricks must naturally be done across. The bricks for mouldings, of which some examples are given in Fig. 227, are easily fashioned by fixing on the outer edge

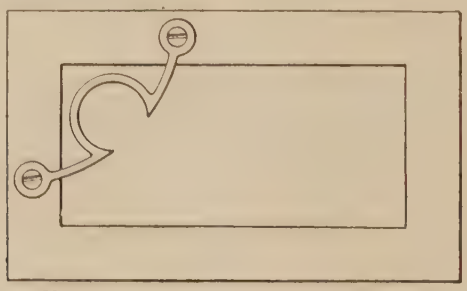

Fig. 228.—Die for Bricks for Mouldings.

of the die a small steel templet, the edge of which is turned towards the inside and to which is given the shape of the profile that is wanted (Fig. 228). The part of the body that is cut off by the templet remains on the brick and is taken away when the latter is dry, before it is charged in the kiln.

When very regular ornamental bricks are required, and when at the same time it is desirable to economise the raw material, it is better to use hollow bricks, which are less liable to get out of shape while drying. These bricks are very much

used in Germany under the name of *Verblender*, where the manufacture of them has become the speciality of certain large brickfields and has attained a degree of perfection that has not been equalled anywhere else. Fig. 229 shows the most used shapes of these bricks as well as the application of them. In

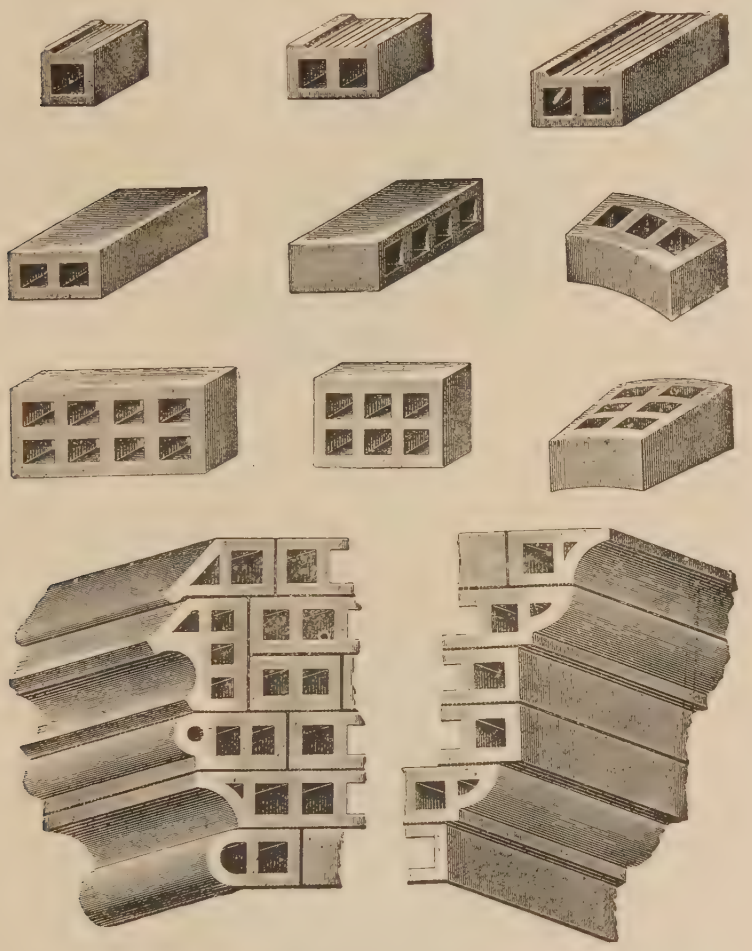

Fig. 229.—Hollow Ornamental Bricks.

the continuous building of the walls quarter and half bricks are used, such as those represented by the two first types.

For the angles are used bricks the holes of which are perpendicular to the joints (Types VII. and VIII.). Ornamental bricks only form a coating that is joined to the ordinary bricks of the same dimensions, which constitute the wall properly so called.

Figs. 230, 231 and 232 show the arrangements of the dies used for squeezing out the most common types. The propellers are those with a single screw of small or medium size. To prevent the surface of the bricks from getting out of shape or being spoilt, they are raised from the cutting table with wooden forks that are put into the holes.

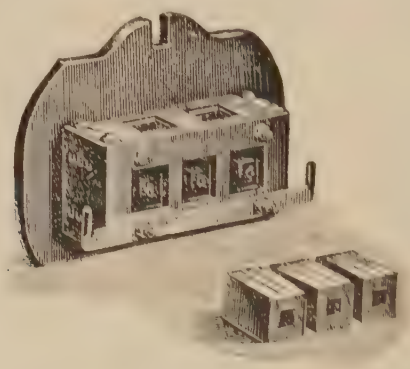

Fig. 230.—Die for Hollow Bricks.

So that the ornamental bricks may be able to suitably resist the weather, it is important that the temperature at which they are burnt should be high enough for the body to be scratched by iron only with difficulty. For this it is necessary to employ a

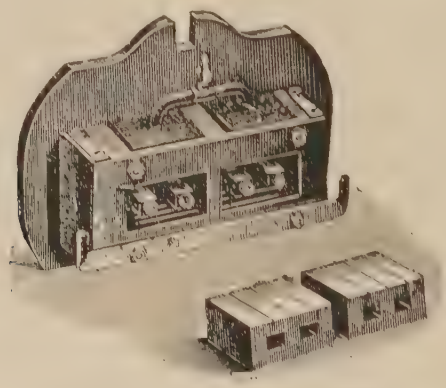

Fig. 231.—Die for Hollow Bricks.

body containing sufficient fluxes for it to have a tendency to vitrify, and also enough refractory materials to prevent it from getting out of shape. Certain natural clays fulfil the requisite conditions; when none such are available they must be made by mixing. In order to obtain pure colours, it is necessary to avoid

the goods coming in contact with the ashes of the fuel. With this object either gas kilns with continuous firing are used (Art. 218), or kilns with continuous firing with solid fuel, but certain precautions need to be taken, of which we shall speak further on (Art. 218).

When the body that is used is not of a sufficiently uniform tint, or when the colour is not the desired one, the surfaces of the ornamental bricks can have a slip. The slip is applied with a brush on the body when hardened or nearly dry. In spite of the care that has been taken to make the expansion of the two bodies agree, it is seldom that very good results can be obtained by this method.

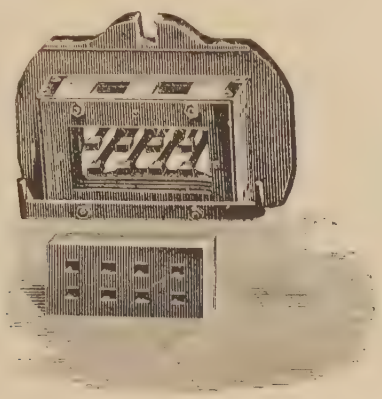

Fig. 232.—Die for Hollow Bricks.

### (*d*) *Vitrified Bricks.*

**210.** Vitrified bricks cannot be scratched by iron, and only with great difficulty by steel. As has already been remarked, they form the transition between terra cotta and stoneware. Sometimes their porosity, though always small, is yet sufficient to rank them with the terra cottas; sometimes they are almost impermeable, and then are really stoneware. They show, at least on the surface, the beginning of a vitrification; the colour of them is either a reddish brown, lighter or darker in tone, and sometimes even almost black, or else a brownish yellow. In the first case the body is ferruginous, and in the second more or less calcareous.

Vitrified bricks are used either as ornamentation, or in hydraulic works, or in masonry that has to bear great pressure.

In the first case their shape can be of the tile form, in the others they are of the same shape as ordinary bricks.

The body for them ought to contain a rather large proportion of fluxes, and have at the same time an important amount of crystalline silica in the form of grains that are relatively large. While it is being heated to a temperature high enough to vitrify the fluxes, the silica ought to remain unattached and form a firm bone-like system in the middle of the mass to prevent it from going out of shape. There is a fairly large number of natural clays that fulfil these conditions. At other times quartzose sand is mixed with fusible clays.

The method of making vitrified bricks is the same as that for ordinary bricks; only the burning must be done at a higher

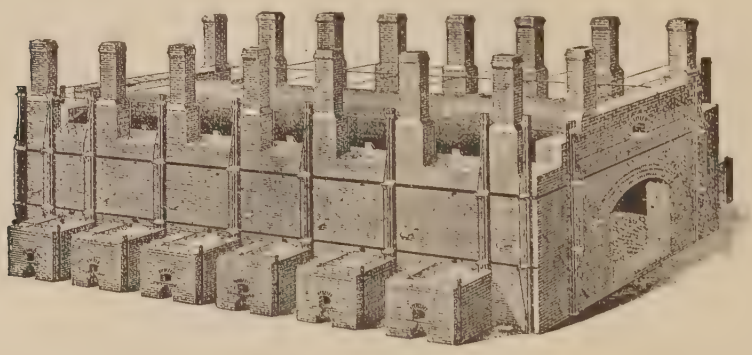

Fig. 233.—Kiln for Paving Bricks.

temperature. Yet it is advisable to avoid moulding by hand, as that makes the goods too porous. As the use of them is generally very restricted, they are burnt in the same kilns, with continuous firing, as ordinary bricks, only heating the compartment in which they are charged to a higher degree. In some countries, such as the Netherlands and the United States, these bricks are used on a large scale for paving the streets.

Sometimes intermittent rectangular kilns, with descending flames, are used for burning them. Fig. 233 represents one of these kilns that is at work in the United States; a section of one was given in Fig. 160 (page 357). It seems to us, however, that it would be more economical to make use of continuous kilns heated by gas.

By using wood fuel the ashes of combustion, carried along

by the draught, are deposited on the surface of the bricks, and, when the temperature is high enough, form on them the most fusible alkaline silicates. These cover the bricks with a thin, vitreous layer.

It has sometimes been attempted to obtain similar effects in kilns with coal firing by throwing salt into them (chloride of sodium) during the hard firing, and by charging the kilns in such a way as at the same time to have a reducing atmosphere. For that the burning ought to be done in intermittent kilns with descending flames, or in kilns with continuous firing with several burning chambers. If the body is decidedly ferruginous, by this method black bricks are obtained that have a certain metallic shine, to which the name of iron bricks has been given.

### (*e*) *Light Bricks.*[1]

**211.** Light bricks are distinguished from ordinary bricks by their apparently small density and their very great porosity. They are manufactured by adding combustible materials to the body, and these are consumed in the baking, thus leaving spaces. Some remarks have been made (Art. 41) as to the raw materials of a charcoal nature that are used for this purpose.

Many manufacturers of ordinary bricks add to the body some powdered coke, coal cinders, coal dust, etc., and thus obtain lighter goods, but these ought, however, hardly to be reckoned as a variety of light bricks. The diminution in weight thus obtained is never very great, and in this method of manufacturing them the reduction in weight is not considered as much as the other advantages that it offers, *viz.*, a more rapid drying, less shrinkage, a more economical burning, etc.

If sufficient mineral fuel is added to a body to make it lighter, the heat given off by that means in burning would make the clay melt, the more so as the fusion would be hastened by the cinders. Light bricks can only be obtained with vegetable fuels that have a small calorific power. The substances most used for this purpose are wood sawdust and chopped straw. The clay must be as plastic as possible, so as to bind together a very large quantity of organic substances,

[1] In America these are termed "Terra Cotta Lumber".

and this latter must also contain as few cinders as possible. Under these conditions one-third of clay can be mixed with two-thirds of sawdust. The proportion of clay can even be reduced to a quarter, by adding straw chopped up into pieces $1\frac{1}{2}$ to 2 inches long.

The body thus obtained can only be moulded in a pasty state. It can be moulded by hand, but only in moulds with hinges. It is also possible to draw it out, but not to cut it by metallic wire. The cutting tables, already described, must be replaced by circular saws. The die must be of rather small section, compared to the diameter of the screw, so as to compress the body a great deal.

The drying is the same as for ordinary bricks. As for the burning, that can only be done in continuous kilns if the proportion of organic materials is equal to that of the clay. Beyond this amount the heat would be too great, and the burning must be done in intermittent kilns, preferably with ascending flames, and with a current of air strong enough to lower the temperature of the kiln. In all these cases only the fuel that is necessary to start it and to attain an even distribution of the temperature should be added.

The light bricks thus obtained can be sawn, turned, and even planed with tools similar to those used for working in wood. This kind of pottery goods is scarcely used except in the United States, where sometimes they replace wood in buildings where there is any danger of fire.

Various other methods of manufacturing light bricks have been suggested, but they have hardly been tried in practice. It is sufficient to mention the mixing of clay with fat bodies—naphthaline, for example. The goods, after having been moulded, are dried in stoves at a sufficient heat for the greasy bodies to melt and run into receptacles, where they are collected and used over again. Lastly, clay can be mixed with very finely powdered carbonate of lime. When burned at a moderate temperature the goods are treated with hydrochloric acid, and chloride of lime is formed, which is removed by washing. These two methods have also been suggested for manufacturing terra cotta filters.

The Romans manufactured light bricks that floated on water. They made use of volcanic products, of silicious tufa, with the addition of a small proportion of clay. Following the same idea, the earth from infusoria can also be used, but the goods thus obtained are refractory, and will be discussed in the following chapter.

## § 2. Tiles.

### (*a*) *Ordinary Tiles.*

**212. Forms and Dimensions.**—The use of tiles dates from very ancient times. In the Louvre there are fragments of tiles from the temple of Artaxerxes Mnemon (B.C. 362). The

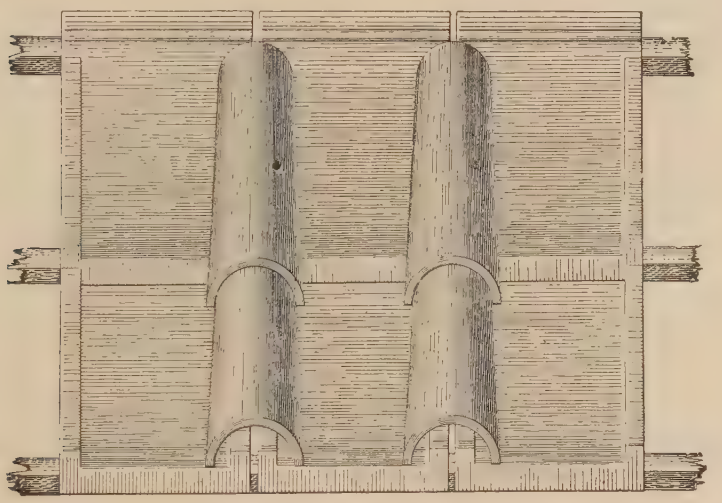

Fig. 234.—Roman Tiles.

Greeks and then the Romans imitated this species of covering, and the shape of the tiles used by these nations, and which were wrongly called *Roman tiles,* is shown in Fig. 234.

They necessitate two patterns being used, one having the form of a fairly thick slab, with two side ridges, and the other that of a slightly conical semi-cylinder. The slab is $15\frac{3}{4}$ to $31\frac{1}{2}$ inches long, $9\frac{3}{4}$ to $20\frac{3}{4}$ inches wide, and 1 to $1\frac{1}{2}$ inch thick. The lap is about $3\frac{1}{8}$ inches. This is possible by the pressing down of the edges to the same depth at the back of the tile. Lastly, a little fillet that projects on the upper face of the tile corresponds to a hollow in the lower face of the tile

that is put over the other, and is for the purpose of ensuring the gaps being filled.

It is very remarkable that this same pattern was used by the Chinese several centuries before our era, and since then by the other nations of the Far East. This tile may be objected to on account of its great weight, but it is of a pleasing architectural aspect, and, from that point of view, certainly superior to all the modern tiles. In the Far East the round covering tiles have often been headed by flowers, which give the roofs a very rich ornamental appearance. Apart from the question of weight, which is sometimes useful, the Roman tile is one of

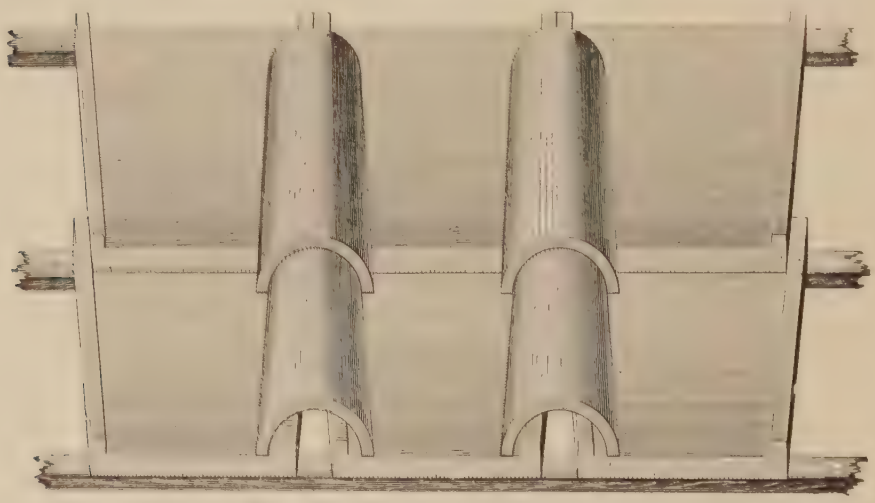

Fig. 235. Tiles of the Middle Ages.

the most perfect types of tiles, and it ought certainly to be preferred to other patterns of which drawings have come down to us. The use of it was general up to the tenth century, then it was modified to give place to the type represented in Fig. 235, in which the slabs are of a trapezoidal shape, which allows of their being covered without necessitating the pressing down of part of the mouldings. This modification involves an enlarging of the covering tile, and a widening of the flat tile. The new pattern was used from the tenth to the twelfth century, and is still made use of in Italy.

After the twelfth century we find appearing in the countries bordering the Mediterranean a new kind of roof, in which was

used only the round covering tile of the Romans. This arrangement, which is shown in Fig. 236, consists in putting on the triangular rafters placed perpendicularly to the ridge some round tiles, somewhat of a conical shape, overlapping each other,[1] the greatest diameter being pointed towards the top of the roof. These tiles are afterwards joined together with similar tiles, but these are arranged in exactly the opposite direction. This pattern of tile is very much used still in the southern countries; the length varies from $16\frac{1}{2}$ to $19\frac{1}{2}$ inches, and the greatest width from 7 to $8\frac{2}{3}$ inches. It makes a heavy roof,

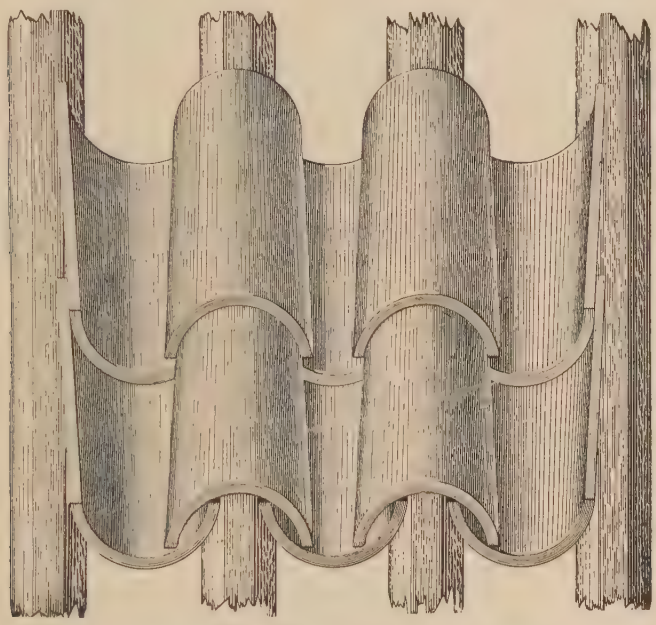

Fig. 236.—Round Tiles.

but protects the buildings very well from heat. Instead of placing the tiles as we have just said, they can also be arranged on a batten, which joins them together by being nailed on to the longitudinal rafters. In that case the lower tiles are fixed on to this batten by means of mortar, and the upper ones are generally attached in the same way, the whole thus forming a kind of masonry. This fastening with mortar, besides, was also possible

[1] This pattern of tile is often called hollow tiles, but this name ought not to be used, first, because these tiles are not hollow in the sense usually attaching to the word, as in hollow bricks for example; and, secondly, because it causes confusion with tiles that are really hollow, of which we shall speak later on.

with Roman tiles and with those of the Middle Ages, at least for the lower layers of the roof.

In Flanders, after the fifteenth century, a new pattern of tile was used, called rib tiles (Fig. 237), having the shape of an elongated S, which was evidently derived from the round tiles, but differed from them not only in form, but also by the

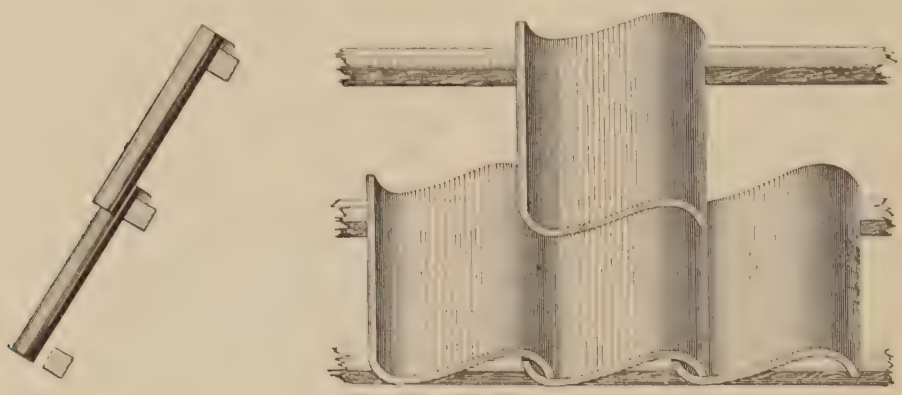

Fig. 237.—Rib Tiles.

addition, on the lower face of the tile, of a small projecting piece, called a hook, which is used for fixing the tiles on to the laths and allows of a great slope being given to the roof.

Towards the end of the thirteenth century there appeared in Champagne and Burgundy a new shape of tile, which had no likeness to a Roman tile, and to which the name of flat tiles

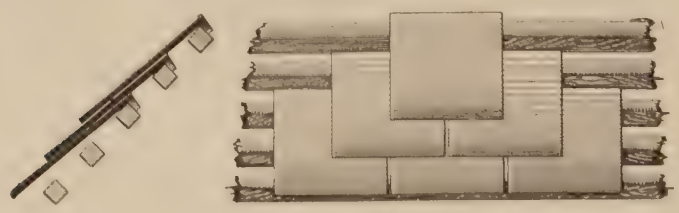

Fig. 238.—Flat Tiles.

has been given (Fig. 238). It had the shape of a rectangle, $11\frac{3}{4}$ to $13\frac{3}{4}$ inches long, by $7\frac{3}{4}$ to $10\frac{2}{3}$ inches wide and 0·31 to 0·86 inch thick. A hook fastened it on to the laths, and two-thirds of its surface was covered over by the upper tiles. Sometimes holes pierced in the tile allowed of one or two nails being put in, which fixed them to the laths.

This pattern of tile is still used in its country of origin, the most usual dimensions at the present time being $11\frac{3}{4}$ by $9\frac{3}{4}$ inches and $9\frac{1}{2}$ by $7\frac{3}{4}$ inches, with a thickness of ·59 to ·70 inch. In other parts the length in relation to the width has been increased, as for example $10\frac{2}{3}$ by 7 inches, and the covering over has been reduced from two-thirds to three-fifths.

By rounding the bottom of the flat tiles, the tiles called scales (Fig. 239) are obtained, the medium size being $10\frac{1}{4}$ or $10\frac{2}{3}$ inches by $5\frac{7}{8}$ to $6\frac{1}{4}$ inches; they are put on in the same way as the preceding ones.

Flat tiles have spread into Germany and the northern countries of Europe, but they are generally made larger and much thicker.

Fig. 239.—Scale Tiles.

Fig. 240.—German Flat Tile.

The upper surface is slightly striated, and the lower part rounded as shown in Fig. 240.

The scale tiles lend themselves very well for the covering of towers and cupolas. In that case two patterns of trapezoidal tiles are used, generally $10\frac{2}{3}$ inches long by $5\frac{7}{8}$ and $5\frac{1}{2}$ inches wide for the large pattern, and $2\frac{3}{4}$ and $1\frac{5}{8}$ inches for the small one. By interspersing, according to the rows, a variable number of the small pattern tiles among the large ones, all kinds of conical shapes can be given to the roof.

In 1851 Gilardoni invented a new system of tiles, which is gradually supplanting, except in some special positions, the tiles derived from the Roman tile, and the flat tiles. This system is based on fitting in the tiles (which allows, while doing away with a covering, of avoiding lath work), and on their undulated form,

which gives them a resistance that is just as great with less thickness. Since Gilardoni's invention a large number of different types have been created, but we will be content to give the two following types as examples, as these are the most usual:—

The tile called lozenged, shown in Fig. 241, is $15\frac{3}{4}$ by $8\frac{1}{4}$ inches; 13 for $10\frac{3}{4}$ sq. ft. are needed; the weight is over $6\frac{1}{2}$ lb.

The Marseillaise tile (Fig. 242) is $16\frac{1}{2}$ by $9\frac{7}{8}$ inches; $13\frac{1}{2}$ for $10\frac{3}{4}$ sq. ft. are required; the weight is about 5 lb.

Lastly, the Boulet tile is $10\frac{2}{3}$ by $8\frac{1}{4}$ inches; 22 per $10\frac{3}{4}$ sq. ft. are required, and its weight is $2\frac{4}{5}$ lb. approximately.

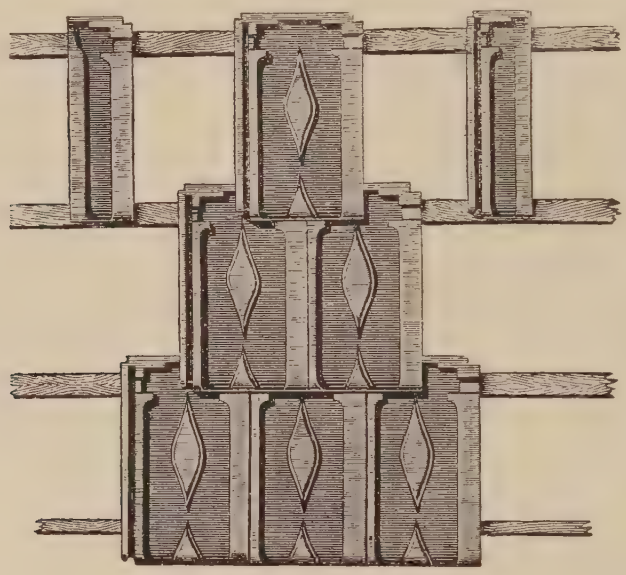

Fig. 241.—Lozenged Tiles.

Instead of fitting in the tiles with vertical and horizontal joints, they can be arranged obliquely, and thus lozenge shape tiles can be obtained. They are little used, and have no other purpose than to obtain decorative effects, so there is no need to carry this point further.

All the tiles for fitting together are fixed on to the laths by means of hooks made to project from the lower faces of the tiles. Sometimes this method of fastening is helped by arranging on this same face a small eyelet hole, through which is passed an iron wire that is bent round the lath. The tile can also be pierced with one or two holes, which are used for holding screws

that are driven into the laths. Lastly, it has been suggested to make a little bolt at the end of the tiles, which would fit into a mortise on the next tile, thus making the whole roof solid. The difficulty of putting them on has generally caused this method to be given up.

About 1882 there was invented, in Switzerland, a pattern of tile which was akin at the same time to flat tiles and to fitting tiles. In fact, the upright joint was made by being covered, and sideways by being fitted together. Several types of this kind have since been suggested; we shall only mention the one that is most extensively used, known by the name of

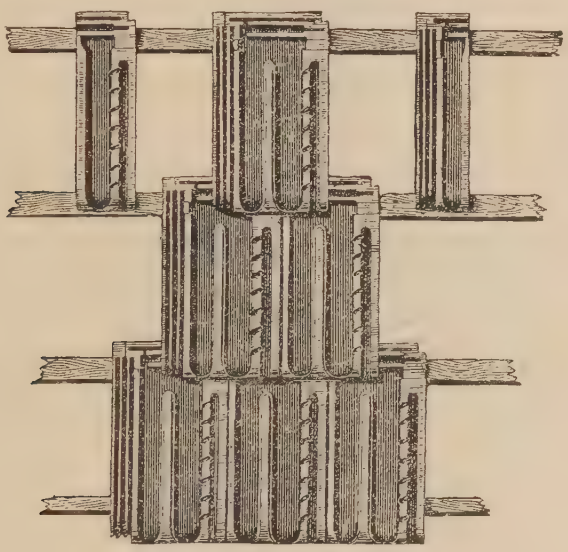

Fig. 242.—Marseillaise Tile.

mountain tile (M. Schmid-Kerez), and which is shown in Fig. 243. These tiles are $15\frac{1}{3}$ by $8\frac{1}{4}$ inches; 17 are required per $10\frac{3}{4}$ sq. ft.; the weight is about 4 lb.

Lastly, it is advisable to mention one other system of tiles somewhat similar to the preceding type, but in which, as shown in Fig. 244, the tiles are hollow and, consequently, give a good insulation against the variations of temperature. They are of various dimensions, and weigh at the rate of 14 tiles per $10\frac{3}{4}$ sq. ft. $6\frac{1}{2}$ lb., and $2\frac{2}{3}$ lb. at the rate of 28 per $10\frac{3}{4}$ sq. ft.

We see that the types of tiles are very numerous, and it is sufficient to look at the collections of patents to see that this

problem continues to exercise the imagination of inventors. The appreciation of their respective merits does not enter into the programme of this work, which is devoted to the manufacture of them. It is sufficient to say that the examples already given are all suitable for excellent roofs, on these two conditions, that the tiles are well made and well put on. The preference given to one or other of them is a question of cost price, of local considerations, and also of method and routine. Besides ordinary tiles, there are a series of pottery pieces that are used in roofing :—

*Ridge tiles*, used for covering the ridge of the roofs.

Fig. 243.—Mountain Tiles.

*Cat's hole tiles*, that have an opening for ventilation; *tiles with windows* for lighting the tops; *tiles with pipes*, used for passing ventilating or draught pipes through, etc.

*Ends of ridge tiles, king-posts, borders, ends of borders, frontals*, etc., etc.

In the catalogues of the principal manufacturers will be found designs for these different parts of the roof, the description of which would be superfluous here.

**213. Moulding of Tiles.**—The moulding of tiles needs more plastic bodies than those used in the manufacture of bricks. In fact, there must be taken into account not only the

moulding itself, but also the porosity of the body. By referring to what has been said about the texture of bodies (Art. 58) we see that it is necessary that the proportion of pure clay should be sufficient to fill all the spaces that separate the grains of the anti-plastic materials. It is true that the perviousness of tiles is only a temporary defect, and that the pores of the terra cotta are quickly sealed up by the dust in the air. But this sealing may cause the development of vegetation on the tiles, and a great perviousness, even though

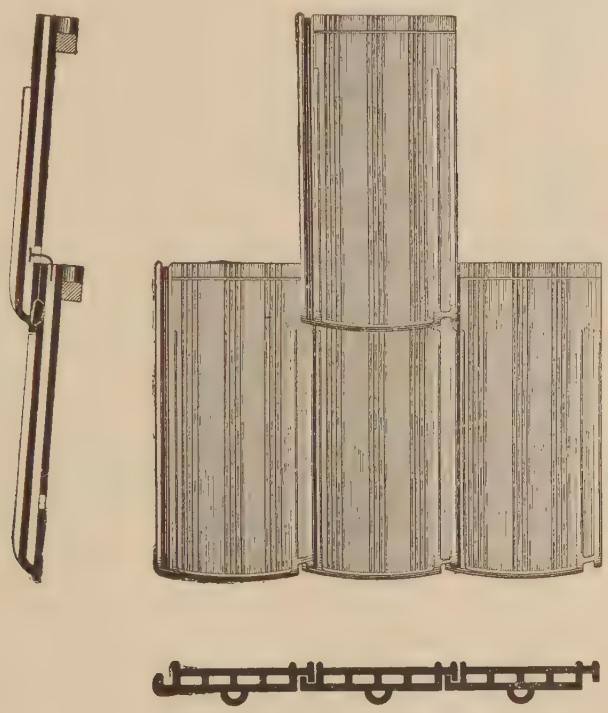

Fig. 244.—Hollow Tile.

temporary, also causes the tiles to be of less commercial value.

Following out this idea, it is advisable to avoid the use of too soft bodies, which, as we have seen, become more porous when dried. This is the common defect in all tiles manufactured in old times by moulding by hand, a defect that it has been attempted to lessen by a great thickness of body and the frequent use of glazes. The moulding by machine with a stiffer body is therefore preferable, but provided that this stiffness is

not exaggerated, if one is not to fall into another defect which is more serious, *viz.*, puffing up, the consequence of which is cracking. We will return to this question at the end of this chapter.

The preparation of the bodies must be carefully done, and they must be absolutely homogeneous if goods that are resistant are to be obtained.

*Moulding by hand* was formerly the only method of making them. For Roman tiles, doubtless, the ribs had to be joined to the slab when moulded in a wooden frame, as was described for plain bricks. As to round tiles, a flat cake is first moulded, and this is placed on a piece of wood that is of the inside shape of the tile. The body, on account of its plasticity, takes the desired curve, the surplus body overlapping the piece of wood is cut away, then it is raised up when the body has sufficiently hardened. The same process is used in manufacturing ribbed tiles. The moulding of flat tiles presents no difficulties, it is sufficient to mention that the hook is fastened to the body when moulded. The tiles for fitting together can also be moulded by hand, by using two plaster moulds bearing the imprint of the upper and lower faces. But on account of the high cost price of it, this method is only used for the manufacture of certain accessories for the roofs, which it would not be possible to manufacture by machine, or at least which it would not pay to so do.

Moulding by drawing out is at present employed for flat or round tiles, or for those of the type of mountain tiles, while the tiles for fitting together are first made by being squeezed out and then moulded in a press, either in semi-soft clay or nearly hard body, or of quite a firm paste. It is necessary to give more details on this subject.

**214. Manufacture by Expression.**—The preparation of the bodies is done either in a paste or dry; in any case the body ought to be of a half soft or semi-stiff consistency, and it ought to be well mixed together at the time when it is put into the propeller. This latter, of a small or medium size, may be of any of the kinds already described. The die plates are nearly always of the arrangement shown in Fig. 72

(Art. 102), the construction of them not offering any difficulties. All the interest in this method of manufacture is centred in the cutting apparatus, which have to change the prism of the body continuously coming out of the die plate into tiles of a different shape. There is a different solution of this question for each type of tile; we will give some examples:—

For flat rectangular and thin tiles the hook can be formed by folding back the body. This solution is shown in Fig. 245. The prism of body is forced by the propeller to pass between two rollers that are turned round by it. The lower one has a projection which corresponds to a hollow on the

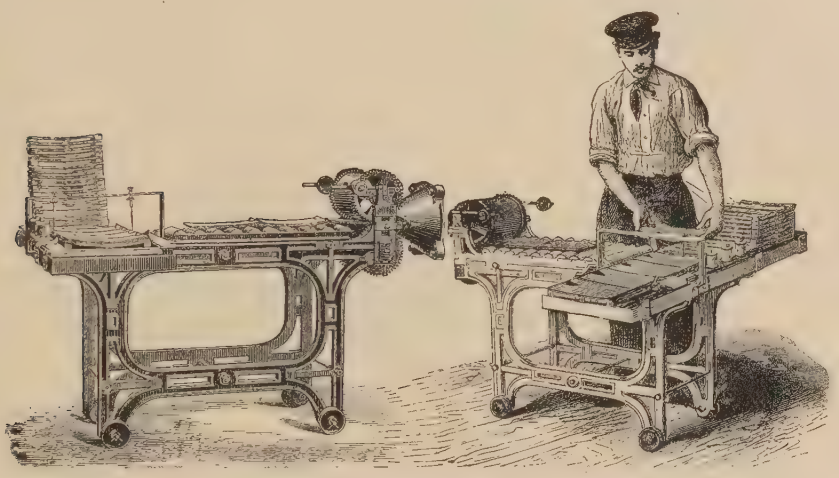

Fig. 245.—Apparatus for Cutting Flat Tiles.

upper roller, and the purpose of which is to press out the paste at regular intervals, to form a hook. A blade placed behind a generator for the upper roller cuts the tile to the right length. This is afterwards put on to a frame by a workman and carried to the drying shed. This apparatus was constructed by M. Joly-Barbot.

When the flat tiles are thicker this method is not applicable. Through a hollow in the die plate, of the same size as the section of the hook, the prism of the body is given the shape shown in Fig. 246, and the roll thus formed is raised in the cutting apparatus by a wire *a b*, except the part that is to form the hook. Fig. 247 shows an apparatus of this

kind, constructed by M. Schlickeysen, in which the tile is cut at the same time to the required length, by making it at the end into an arched form so as to obtain the type shown in Fig. 240. The tile when cut reaches at the end of the board a balanced piece; it is covered over with a wooden

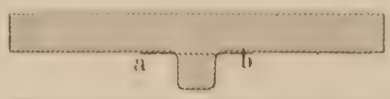


Fig. 246.—Manufacture of Flat Tiles.

frame, and the whole turned over by holding it in the frame with the hand. The tile thus placed on the frame is carried to the drying shed, while the balanced part of the board is put back into its original position ready for another tile. In this way 600 to 700 tiles an hour can be made.

M. Diesener has tried to make several flat tiles of the

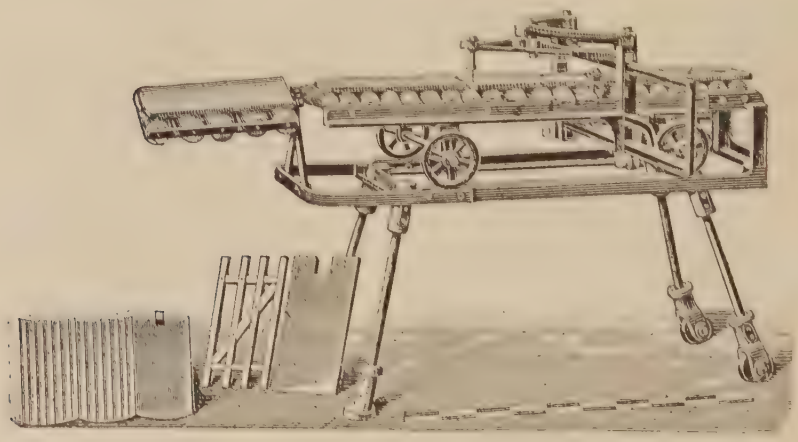

Fig. 247.—Cutting Apparatus for Flat Tiles.

preceding type at one time. For this purpose a length of body is passed out of the die plate, having a sectional shape as shown in Fig. 248, which is cut to the length of the tile by a first cutting apparatus. Then the bundle of tiles is pushed by hand into a second apparatus, which has a series of horizontal wires that divide it up, according to the dotted lines in the engraving, into four tiles, keeping the parts of the fillets *a* which are to form the hook. The whole is then put into the drying sheds, and the tiles are separated only when dry by

taking away the small pieces *a* and *b*. About 1,200 to 1,600 tiles an hour are made.

The mountain tile already described (Fig. 243) is made by a cutting apparatus. In the same way as for the preceding flat tiles, the prism of body must be cut of the desired length, and a part of the fillet be raised to form a hook. But, besides this, it is necessary to press down a length equal to the projection of the mid rib of the covering tile. These various operations are easily done by a single workman. The tile arrives at the end of the board quite finished, is covered over by a frame, and balanced as shown in the engraving.

This cutting apparatus, made in France by the Society of Studies and Inventions, can produce 500 tiles an hour.

Cutting apparatus have been made in Germany furnished

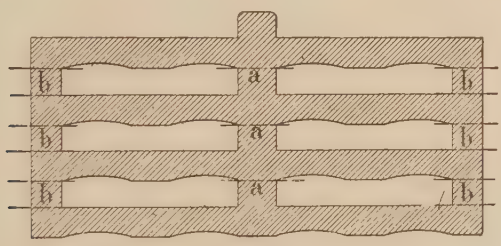


Fig. 248.—Method of Making Flat Tiles in a Packet.

with punches, by which tiles can be given some projections that it is impossible to get by the die. It has also been attempted to alter the profile of the die from time to time. These arrangements are not to be recommended, and there is very little sense in turning a cutting apparatus into a press, under the pretext of avoiding moulding by a press.

As a last example of the method of manufacture by expression, that of round tiles may be mentioned. Various very ingenious systems have been suggested for solving this problem, which is somewhat paradoxical at first sight, of making by a die a body of conical form. The following solution is the simplest: A length of body is passed out of the die, of the shape shown in Fig. 249; this length is at once divided by a horizontal fixed wire, *mn*. Then, the tile having been cut to the desired length on an ordinary cutting board, the upper circular part

is raised by means of a wooden conical block (Fig. 249) of the shape of the interior of the tile. The sheet of clay, thanks to its plasticity, fits on to the punch, following the dotted contour, *abe, def.* It is then sufficient to make this punch slip along an iron wire stretched so as to cut the two triangles of the body, which are larger than the lower face, and to place the finished tile on a little board. This process allows 250 round tiles to be made in an hour. They can also be made equally well by a press.

**215. Manufacture in a Press with Semi-Soft or Semi-Stiff Body.**—As has just been said, the moulding by a press ought to be preceded by a roughing out in the die plate. The body, when suitably prepared as if for the preceding method of

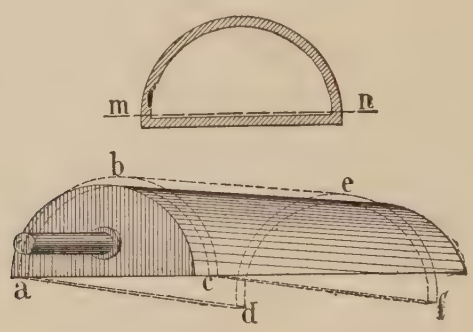


Fig. 249.—Manufacture of Round Tiles.

manufacture, is put into some kind of propeller, from which it comes out in the form of a prism approximately of the length of the tile, and is divided horizontally by several fixed wires, the spaces between them corresponding to the thickness of the tile. Fig. 250 represents an example of a machine of this kind, with cylindrical propellers surmounted by two pairs of rollers, made by MM. Chavassieux Long, which will manufacture about 1,000 slabs an hour.

The length of body when divided is cut to the measure desired with an ordinary cutting machine; the "batts" thus obtained are then put into a heap and kept damp for about twenty-four or forty-eight hours.

The "batts" are afterwards separated from one another and put between the moulds of a press. These moulds are to crush

them, the working of them having been described in Art. 110; it is enough to mention the way in which the metallic moulds are covered over with a layer of plaster. For that two pattern models are used made of polished cast iron, which are a reproduction of the upper and lower faces of the tile. These pattern models are carefully cleaned by means of an emulsion of soft soap; then, after being covered with a thin layer of soap by a brush, the plaster prepared as described in Art. 106 is poured over them. A certain quantity of plaster is run in the same way into the metallic shells, then each pattern model is put on the corresponding shell, the whole is

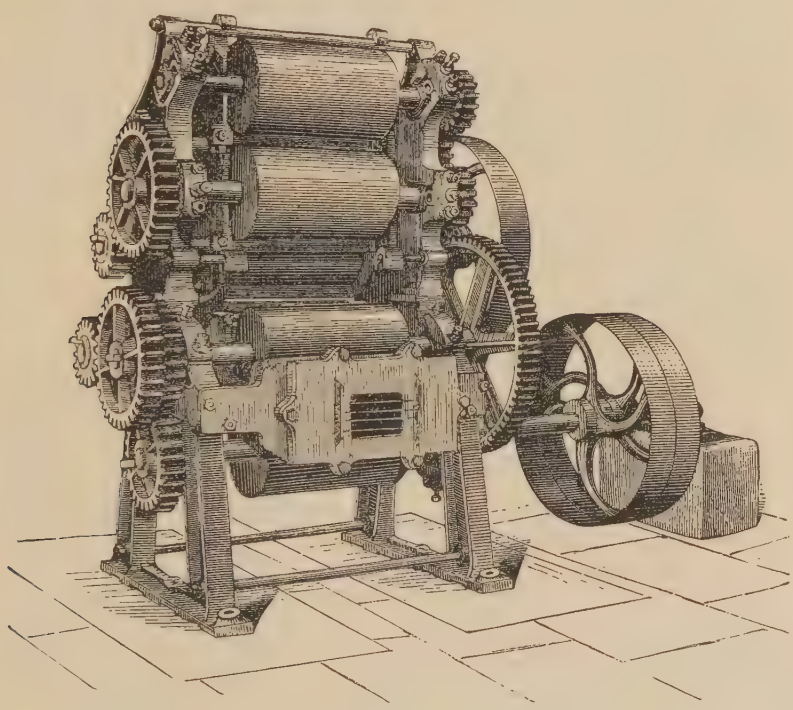

Fig. 250.—Machine for the Cakes of Body.

pressed for about half an hour, the pattern model is removed, and the shell, covered with a layer of plaster, is dipped in water for an hour. The mould is then ready for use.

Fig. 251 represents at the upper part the two shells, and at the lower part the two pattern types of a Marseillaise tile. The pressure of the pattern model against the shell is usually

done by means of a screw fixed on a wooden table by a cast-iron arch (Fig. 252).

The presses used for manufacturing tiles of semi-soft or

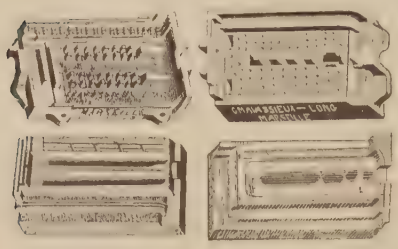

Fig. 251.—Patterns and Moulds for Tiles.

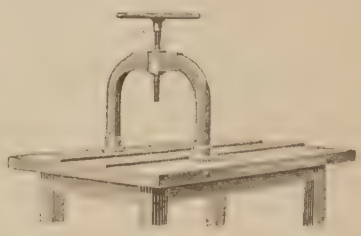

Fig. 252.—Press for making Plaster Moulds.

semi-stiff paste are all with tappets or eccentrics, and act by pressure. Fig. 253 represents a machine of this kind, with two lower moulds and an upper mould, made by MM. Chavassieux

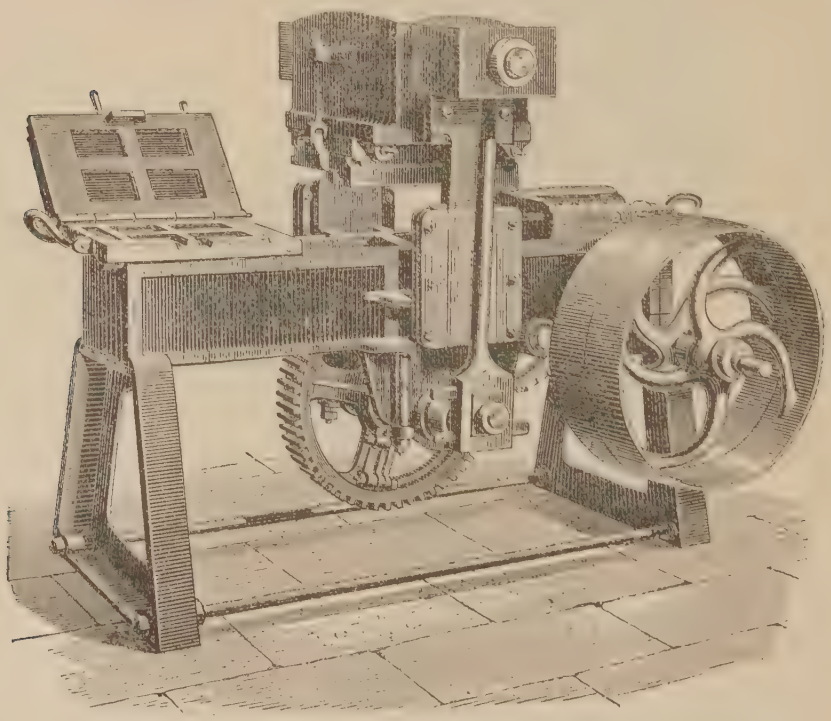

Fig. 253.—Press for Tiles.

Long. Each lower mould is slipped by turns under the upper mould, to which the motor gives an alternate motion, from the top to the bottom and from the bottom to the top. They are

taken out of the mould by placing a framework on the tile, which remains sticking to the lower mould, then holding this board with the hand and turning the mould over on to it, so as to give it the position shown on the left hand side of the

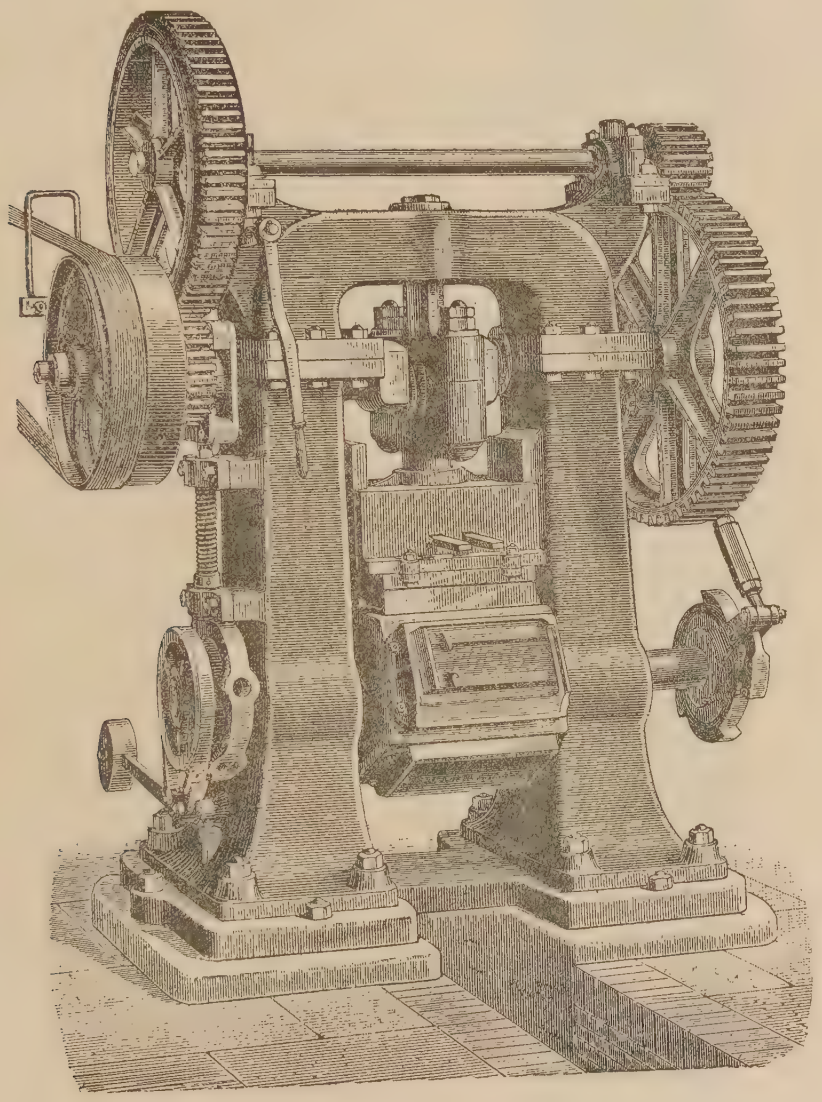

Fig. 254.—Tile Press.

engraving. By employing only one workman as moulder this machine can produce about 250 tiles an hour; it may reach 400 tiles an hour with two moulders.

For larger quantities "five piece" presses are used, invented

by M. Schmerber, an example of which was given (Fig. 109) on page 229. This machine, made by MM. Boulet et Cie, produces about 500 tiles an hour with a single moulder working it. Fig. 254 represents a machine of this kind made by M. Pinette, the working of which is identical with that of the preceding press.

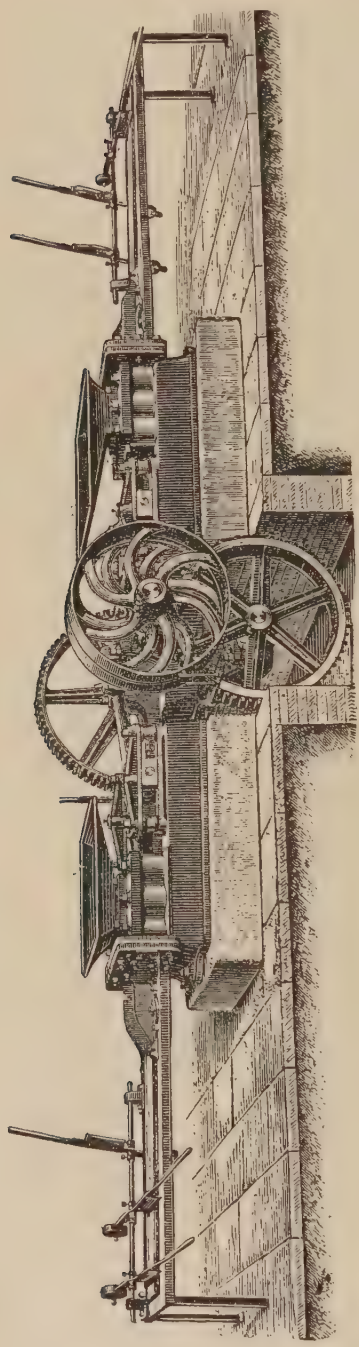

Fig. 255.—Machine for Slabs (Cakes).

The tiles, when thus moulded and placed on little boards, are carried to the drying sheds, where, after having been dried for some time, and have acquired the consistency of stiff body, they are clipped, that is to say, are stripped of the lines caused by the body oozing out between the moulds.

**216. Manufacture in a Press with Stiff Body.**—The moulding of tiles in stiff body is done in the same manner as moulding in semi-soft or semi-stiff body; but other machines must be employed, because of the greater pressure which must be exerted to draw out the cakes and mould the tiles. The body naturally must be prepared as was described in Article 89 (p. 160).

Screw propellers cannot be used, and it is necessary, for the making of the slabs, to have recourse to piston propellers, or else to cylindrical propellers. The first solution is adopted in the machine shown in Fig. 255, made by M. Pinette, which is

composed of two condensing boxes, one being worked while the other is being filled. The body comes out of the die in the form of a prism having a width and thickness equal to that of the

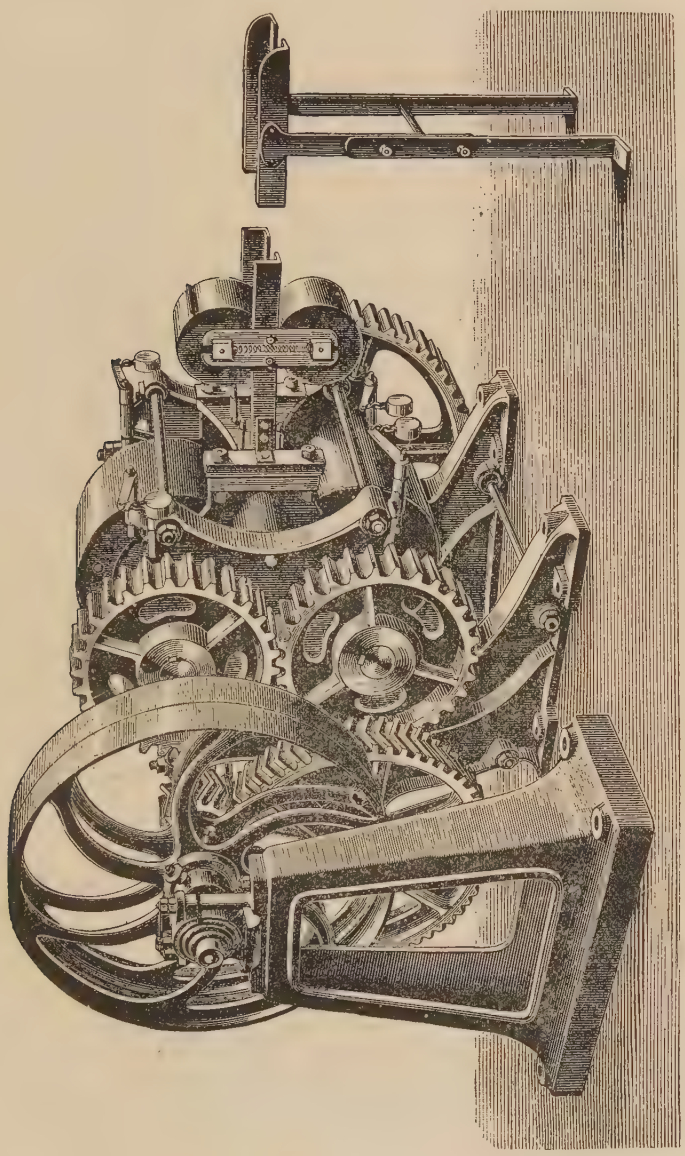

FIG. 256.—Machine for Slabs (Cakes of Paste).

"batt," which is afterwards cut off at the desired length by means of balanced knives. According to the pattern, this machine can turn out from 400 to 1,000 slabs an hour. With a single condensing box the yield is reduced to 300 slabs.

While speaking about the manufacture of hollow bricks of large size we said that a rather firm body and piston propellers should be used. The preceding machine is specially suitable for this style of manufacture.

Fig. 256 shows a machine for making slabs in which the propelling force is by means of a cylinder. The body, on coming

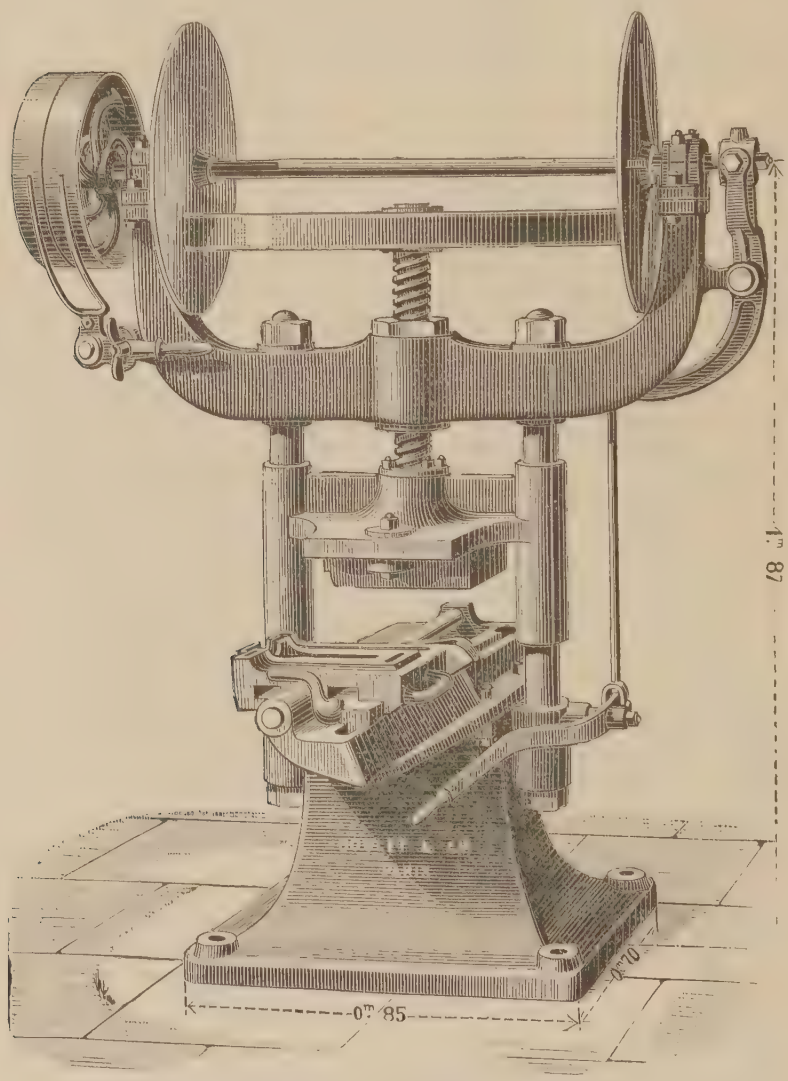


Fig. 257.—Tile Press.

out of the die plate in the same shape as in the preceding machine, is forced to pass between two rollers that it sets in

motion, and one of them has an edge which cuts the prism of body into pieces corresponding to the length of the slabs. It must be mentioned that in this machine, constructed by MM. Boulet et Cie, the use of cylinder propellers does not allow of the body being of such a stiffness as it may have when piston propellers are used.

Contrarily to what is done when manufacturing with semi-soft body, the cakes of hard body are pressed immediately they are squeezed out.

The moulds that are used in this case cannot be of plaster, which would be broken; polished cast-iron moulds must be used, which are oiled to prevent them sticking. Often it is advisable to grease the cake itself before it is put under the press.

For making tiles of hard body striking presses are principally used, such as were shown in Figs. 106 and 107 (pp. 226 and 227). Fig. 257 shows a machine of this description, but stronger, arranged for making ridge-tiles, but available also, by changing the moulds, for pressing tiles. The lower mould being in the position shown in the engraving, the cake is put into it, then it is pushed under the upper mould. Then, by working the side lever, one of the vertical discs is brought in contact with the upper horizontal fly-wheel, which causes the screw to fall. The pressure exerted is in proportion to the active force accumulated in the fly-wheel. By a second movement of the lever the other disc is made to act, turning in the opposite direction, which moves the screw up again. The lower mould is then brought forward and balanced. This machine, made by M. Pinette, can press 300 to 350 tiles an hour, reckoning them at 13 to 14 per $10\frac{3}{4}$ sq. ft.

Sometimes eccentric presses are also used, but these machines, which only give a definite pressure, are less useful than the preceding press, which is called a friction press, and which allows, according to the stiffness of the body and the size of the object to be made, of graduating the pressure by the distance given to the screw, and by exerting two or more successive pressures.

When they come out of the press, the tiles are placed on a turn-table and clipped by hand. It has often been tried to do this clipping by machine, by placing the tile under a frame bearing sharp edges which, when they descend, come and cut off the edges. Up to the present the use of these machines has not spread.

**217. Drying.**—It is only when tiles are made of very stiff body that they can be carried and put on the stages without being supported by wooden frames. Nearly always the latter are indispensable. The shape and dimensions of them depend on the type of tile. For example, Fig. 258 shows one of the arrangements that is most used; three wooden strips are nailed on to two cross pieces. As the tiles have to dry on these frames, and as this drying lasts usually from ten to twenty days, if artificial drying is not employed, the result is that the number of frames used, even in a tileworks of moderate size, is considerable. It is necessary in making them to use good dry wood, which will not easily warp by the damp of

Fig. 258. Framework for a Tile.

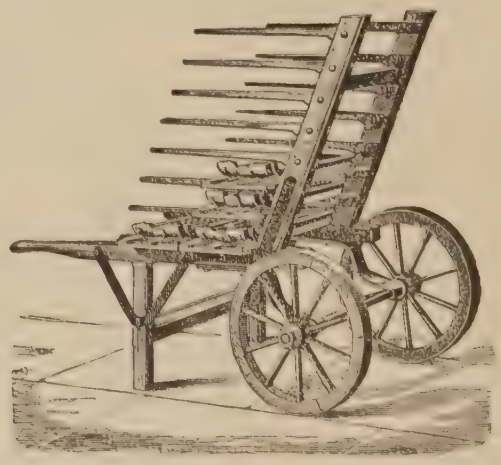

Fig. 259.—Wheelbarrow for Tiles.

the body when fresh moulded. The warping of the frame naturally involves that of the tile as well.

The methods of carrying the tiles into the drying sheds are the same as those used for bricks; there is therefore no need to repeat them. It is sufficient to say that the little waggons are scarcely ever employed, and that wheelbarrows, instead of being flat, are usually of the kind shown in Fig. 259.

The drying of the tiles is generally done in large ventilated buildings over the kilns, the waste heat from which is thus made use of. More rarely independent sheds are used. The different kinds of artificial drying sheds, formerly described, naturally can just as well be used in this case.

As tiles generally weigh from $4\frac{1}{2}$ lb. to 7 lb., the amount of heat and the volume of air required for drying them are about the same as for plain bricks, and it is sufficient to refer to the calculations made in reference to the latter. The duration of the drying is, however, decidedly shorter, on account of their small thickness.

**218. Burning.**—The same as for bricks, the burning of tiles

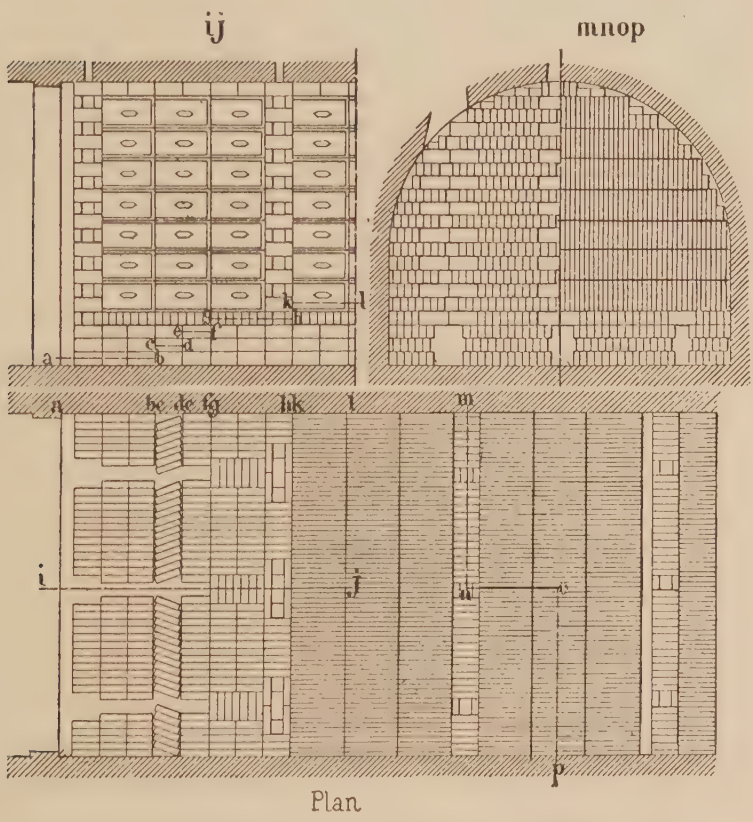


Fig. 260.—Charging of Tiles and Bricks.

ought to be done in kilns with continuous firing, except for small quantities, in which case semi-continuous kilns must be used. This is only quite exceptional, as, for example, in small factories in the colonies, when intermittent kilns with ascending (Fig. 158) or descending flames can be used.

In burning tiles, as in that for ornamental bricks, the fuel or the ashes must be prevented from coming in contact with the goods. When, as is most frequently the case, plain or

hollow bricks and tiles are all manufactured at the same time, it is wise to use by preference the kiln shown on Fig. 221 (page 487). Then the bricks can be used to form the heating shafts, and to cover the bottom of the kiln. This method of charging, which needs 40 per cent. to 60 per cent. of bricks, is shown in Fig. 260.

The manner in which the tiles are placed in the kiln depends on their shape. But one should always try to avoid their warping while burning by leaning them against one another. The tiles are usually placed in twos, being put against one another in such a way as to take as little room as possible, and to protect the projecting parts.

The tiles for fitting together are packed close together, the spaces that are left between them being sufficient to ensure the circulation of the gases and flames.

The same applies to round tiles, which are placed upright on one another. As to flat tiles, it is not so easy to charge with them, as spaces must be left in that case. When they are thin they cannot be charged in bulk, but they must be put in slips, by using bricks or special pieces when necessary, so as to form cases for them. This method of charging ought to be used for other tiles as well. Then they are to be burnt at a temperature approaching that at which they will get out of shape.

The simultaneous burning of hollow bricks and tiles gives excellent results. Owing to the slight thickness of these goods the burning can be very rapid, and the thermic yield of the kiln be above that when plain bricks are burnt. By admitting a proportion of air double the quantity that is theoretically necessary, the kiln can be made to work with the following thermic conditions:—

| | | | |
|---|---|---|---|
| Heat produced by combustion . | 100 | Heat theoretically necessary . | 100 |
| Heat furnished by being collected | 50 | Heat lost by heating the walls . | 20 |
| | | Heat lost by radiation . . | 25 |
| | | Heat lost through the chimney . | 5 |
| | 150 | | 150 |

In this case then the yield of the kiln can reach 100 per cent., the heat furnished by being collected together compensating for the heat lost.

When it is necessary to make tiles exclusively in the preceding kiln, the heating shafts that were made of bricks to be burnt can be replaced by a kind of fixed furnace of firebricks, put about $6\frac{1}{2}$ feet apart. Fig. 261 shows an arrangement of this kind proposed by M. Haedrich. The fuel thrown in through a central opening falls on the bricks put in steps between two walls that are half a brick thick. The air follows the path shown by arrows. The ashes remain between the walls without diffusing into the kiln. This arrangement makes it much more difficult to look after the kiln, necessitating too much space being lost in charging, and the furnaces often have to be repaired. Except in certain special cases, it is better to

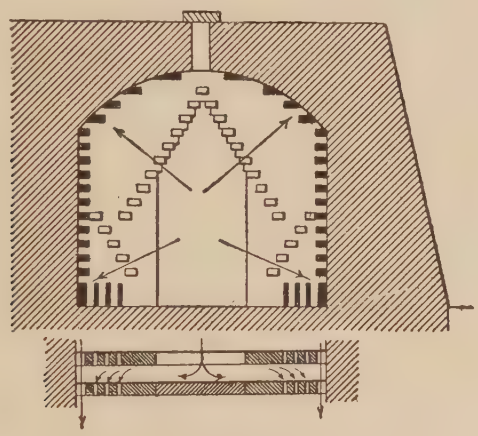

Fig. 261.—Fixed Firebrick Furnaces.

use gas for burning them, by adopting the arrangement for the burners that are called candles, like those shown in Fig. 170 (page 368). Fig. 262 shows the whole of a kiln of this description with more details. The gas, coming from the gas generators through two lateral channels, is carried to the burners by movable iron pipes. The charging is done in trenches (A), leaving between them a space in which are the burners, and where the combustion takes place; the gas passes out perpendicularly with the circulation of the air. The working of this kiln is the same as that of the kiln formerly described in Fig. 221 (page 487).

Burning by gas has the advantage of doing away with the defects due to the contact of the carbon, the heating is more

rapid, and the temperature more easily regulated. On the other hand, it is more costly to put in, and the thermic yield of the kiln is lessened by the loss due to gasification, which was valued in Art. 159.

Continuous kilns with trenches also solve the problem of the exclusive burning of tiles. The principle of them has already been described (page 370), and Fig. 263 shows the whole arrangements of a kiln of this kind. The tiles are charged in trenches equal to the length of a tile, and separated from one another by spaces equal to the width of the bars.

In these kilns, the air necessary for combustion is passed directly under the gratings and cannot be collected again.

If, however, as is usually the case, the kiln works with an excess of air, this excess of air can be made to come from the back, as in the kilns we have just described, and on coming out a certain amount can be collected.

The thermic balance of these kilns is the following, approximately :—

| | | | |
|---|---|---|---|
| Heat produced by combustion | 100 | Heat theoretically necessary | 60 |
| Heat furnished by collecting | 15 | Heat lost by the heating of the walls | 20 |
| | | Heat lost by radiation | 25 |
| | | Heat lost through the chimney | 5 |
| | | Heat lost through an incomplete combustion | 5 |
| | 115 | | 115 |

The yield is reduced to 60 per cent.

**219. General Arrangements of Tile Works.**—The value of tiles is usually $2\frac{1}{2}$ to 3 times as great, in proportion to the weight, as that of plain bricks. On the other hand, the deposits of clays suitable for the manufacture of tiles are less widespread, so that tile works are factories less local than brickfields. The cost of transport is also very high compared to the value of the goods, but factories, when well placed, can yet send out their goods over a fairly large radius, and even sell them for exportation. Under these conditions, small tile works, that is to say those which cannot use continuous kilns, are rare, and only owe their existence to entirely local circumstances. Besides, we must remember what has already been said on the subject of the inferior quality of tiles when moulded by hand,

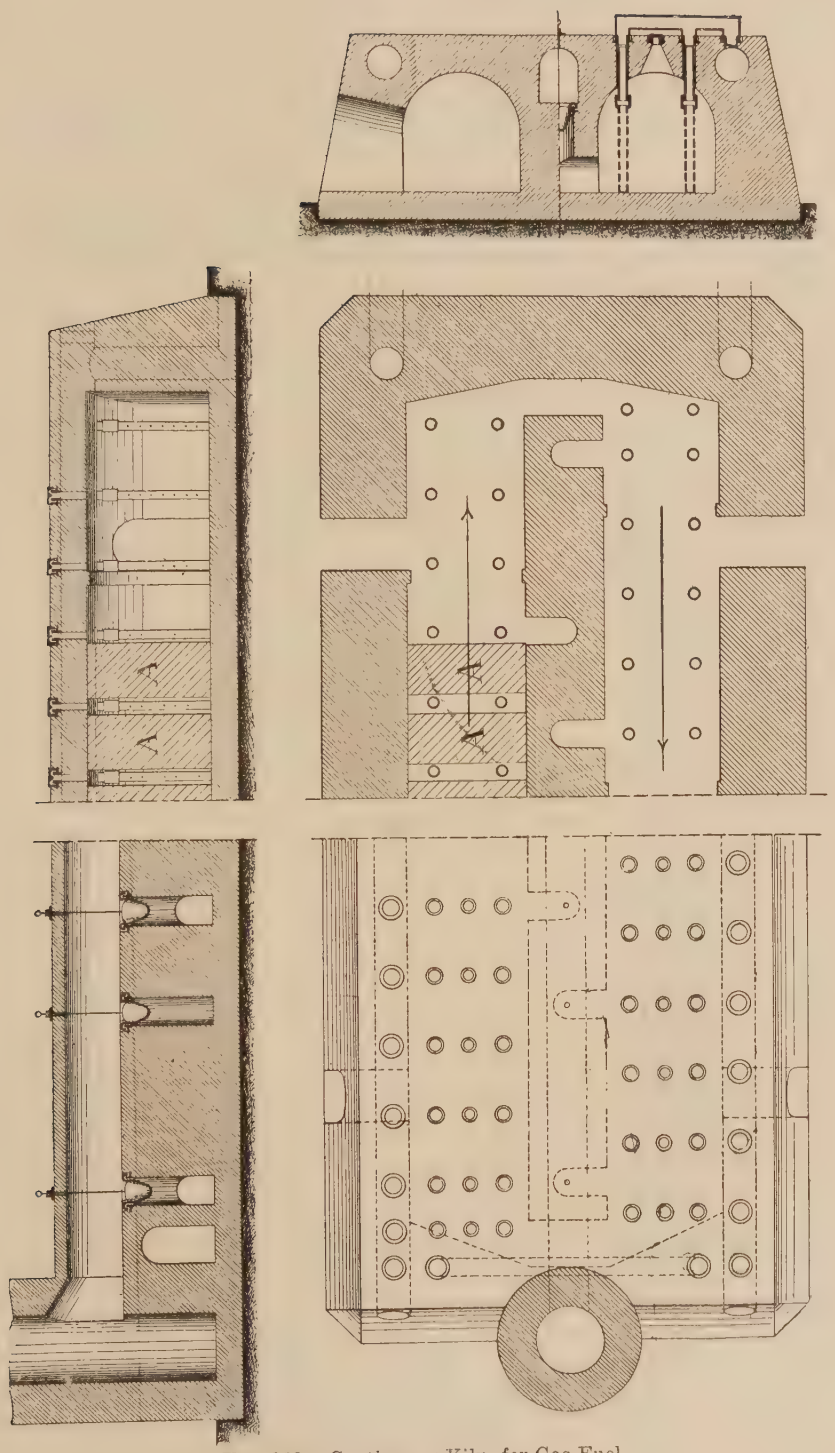

Fig. 262.—Continuous Kiln, for Gas Fuel.

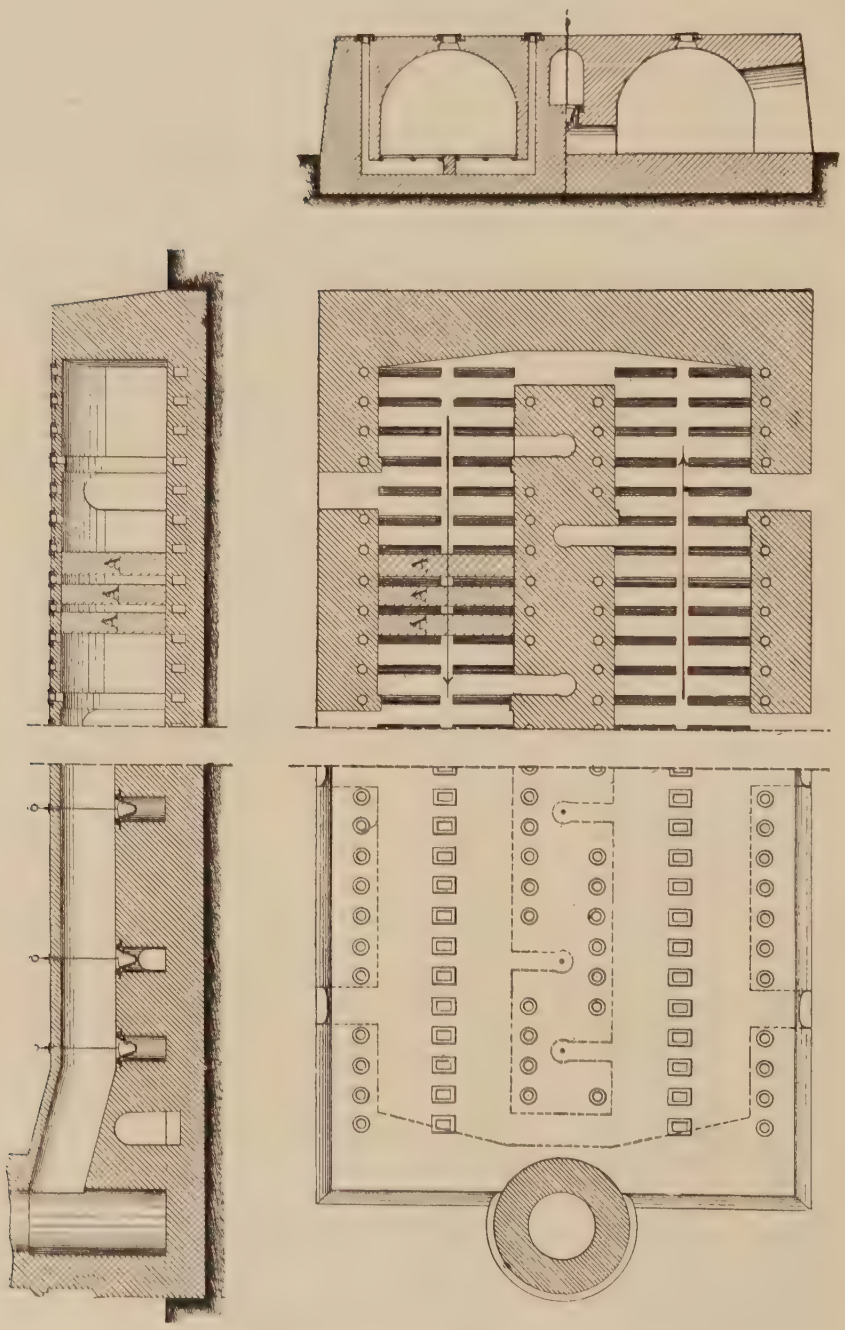

Fig. 263.—Continuous Kiln, with Trenches.

and notice that manufacturing them by machine and preparing the body well can only be done by using a steam engine.

Setting aside the small factories, which become less and less numerous, let us remark that most tile works are placed by the side of clay pits; it is only very exceptionally that the raw materials are transported, so as to start them near the large centres of consumption.

The differences which there are in the methods of manufacture employed in the tile works are not sufficient to make important variations in the general arrangements of them. All the tile works recently constructed consist of large buildings over the kilns, containing on the ground-floor the rooms for preparing the bodies and for making the tiles, while the upper floors are kept for drying sheds.

### (*b*) *Black Tiles.*

**220.** The black colour of unglazed terra cottas can be obtained by five methods:—

1. Colouring the body by means of oxide of manganese.
2. By an application of a black slip on the body.
3. By dipping it in tarry materials.
4. By burning them in a reducing atmosphere charged with hydrocarbons.
5. By burning them in saggers containing powdered carbon.

The first two methods have already been described, but, on account of the rather high price of the colouring oxide, they are only seldom used for ordinary terra cottas for building purposes.

*Tarring* is one of the methods principally used for tiles. It is done by dipping the goods in the liquid tar. For this purpose it must be sufficiently fluid to sink into the pores of the terra cotta; therefore it is absolutely necessary to heat it. If cold terra cottas are dipped in it, they absorb it only on the surface, and the black colour quickly disappears from the action of rain. On the other hand, by heating them first to 50° or 60° C., the tar penetrates to a depth of ·0787 or ·118 in., and makes goods of a more or less dull unglazed black colour.

It must not be thought that tarring helps the terra cottas

to resist the weather. It is rather the opposite that takes place, as we shall see at the end of this chapter, when speaking of the tests for building terra cottas.

The process which consists in colouring terra cottas black, by means of a special kind of burning, is called by the name of *blueing*, because when the bodies are suitable the black colour has bluish, metallic reflections. The kilns for blueing, on account of the extremely reducing atmosphere that they ought to have during the cooling, are necessarily intermittent. They can be built in different ways. Fig. 264 shows, by way of an example, one of the arrangements most used (O. Bock). A series of tunnel kilns is placed side by side, communicating with a chimney through a central subterranean channel. The heating is by two fireplaces at the ends. Two shafts (funnels)

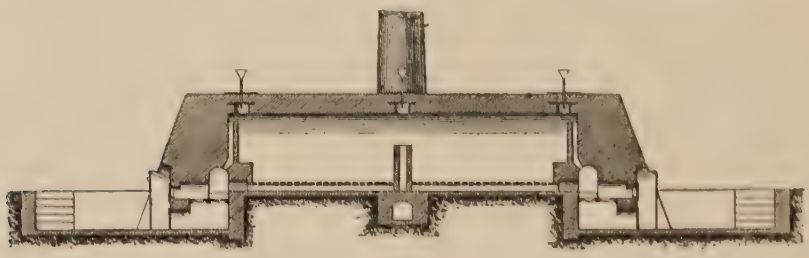

Fig. 264.—Kiln for Blueing.

are used for pouring in the oil, of which we shall speak later on. Hardly more than two burnings a month can be done, the cooling lasting from seven to ten days. The charging, warming, and burning properly so called are done in the same way as for ordinary terra cottas. It is only when the maximum temperature has been reached that the special operation of blueing commences. Formerly for this purpose green wood was used; with this they charged the furnace, then shut all the openings of the kiln and let it cool slowly, entirely by radiation. Now it is preferred first to entirely isolate the burning space, and then pour through special shafts liquid hydrocarbons, such as tar, or the oils arising from the distillation of petroleum or schist. Under the influence of heat these bodies are decomposed, and a deposit of graphite is formed in the interior of the pores of the terra cottas which colours the whole mass. If the bodies do

not contain iron, or if the latter is combined with the lime which may be in them, the colouring is of a more or less greyish black, with a more or less dirty look. If, on the contrary, the body is ferruginous, the peroxide is changed into protoxide, perhaps even partially into metallic iron, and gives a very beautiful blue metallic shine to the terra cotta. From $17\frac{1}{2}$ to 55 lb. of oil are needed for a thousand tiles, this oil being put in two or three times at intervals of one or two hours.

For this operation to be very successful, it is absolutely necessary for the kiln to be perfectly air-tight, and for no air to get in, as that would burn up the graphite, as long as the temperature of the goods does not fall below dull red. When this temperature is reached the cooling can be hastened without disadvantage by opening the upper orifices of the kiln or the damper of the chimney. It must be noticed that, as a consequence of the cooling, there is a tendency for a partial vacuum to be formed in the burning space; also, too many precautions cannot be taken to keep this closed in a suitable way and prevent the outer air from getting in.

A beautiful brilliant black can be given to terra cottas blued in this way by rubbing with a brush full of blacklead. But as this shine is not durable, the process ought to be absolutely condemned. Besides, it can easily be recognised by the black marks that the goods leave on the fingers.

Lastly, a black colour can be given to tiles by charging them in saggers, or in a kind of box formed of bricks or terra cotta slabs. There is thus formed, in the saggers or boxes, an extremely reducing atmosphere, which acts in the same way as that of the blueing kilns. Although this method has the advantage of not needing special kilns, the difficulties of charging them are somewhat great; also it is scarcely used, as we shall see further on, except for paving tiles and ornamental pottery.

### § 3. Paving Tiles.

**221.** Paving tiles are used either for paving or for putting on walls. In the first case they are either of terra cotta or of stoneware; in the second case they are of glazed terra cotta,

faience, stoneware, or porcelain. At present we shall speak only of polychrome paving tiles in unglazed terra cotta and without ornament.

It is often rather difficult to distinguish paving tiles of terra cotta from stoneware ones; we shall here only talk of those the body for which is decidedly porous and relatively softer, thus making them rank without doubt among the terra cottas. The others will be mentioned in the chapter devoted to stoneware.

The shape of terra cotta paving tiles is usually either square or hexagonal, the side of which or the diameter of the circumscribed circle varies from 13 to 6 inches, the most usual size being $7\frac{7}{8}$ inches. The thickness depends on the other dimensions, on the method of making, and on the nature of the body, varying from 0·39 to 1·96 inch.

The body used for manufacturing paving tiles is the same as that for making tiles, and the methods of moulding are identical.

Moulding by hand in a wooden frame is still sometimes employed, principally for large paving tiles, or rather for slabs, but machine moulding, which gives firmer goods, is preferable in all cases. The same as for tiles, they can be made by squeezing out, when the paving tiles are finally cut to the desired dimensions on a very simple cutting board, or even by preparing a slab by means of drawing, which is afterwards moulded in a press. When this is roughed out of semi-soft body it is allowed to harden before being pressed, as has been described for bricks. When, on the other hand, it is made of firm body it is pressed as soon as it is drawn out.

Ordinary paving tiles that do not need care are in the shape of prisms, the base of which is the square or hexagon, and the height is the thickness. As they are put on in a bed of mortar, they have the disadvantage of showing the joints all round them. This defect can be remedied by giving the paving tiles the shape of a truncated pyramid, the larger base of which is the face that shows. When they are put on the sides of this face are made to touch in such a way as not to let the joints show, the mortar settling in the triangular space, open at the bottom, formed between the two paving tiles side by side.

In the first case the moulding may be done by means of all the presses that have already been described. In the second case special arrangements must be employed. The most simple method, if not the most economical, consists in moulding by hand or squeezing out and then repressing a rough paving tile slightly larger than is wanted, and afterwards trimming it by hand. For this purpose to the lower face of this paving tile, put on a slab of marble, is applied a metal templet, having the dimensions of the base of the paving tile, but the projecting sides of which are sloped and narrowed towards the top. By applying the edge of a knife round these sides the body is cut off obliquely, and a paving tile is thus cut into the form of a truncated pyramid as desired. So that the templet shall not get out of place during the cutting, there are little points on it, which press into the body and keep the whole steady.

By using the machine shown in Fig. 265 a rough-shaped paving tile can also be pressed out, and the desired shape be given to it. There are two moulds, which turn round on one of the uprights of the press, which by turns are used for taking out of the moulds and in pressing. The moulds are formed of a bottom which is joined to it and a frame moving on a hinge, the sides being sloped towards the bottom. The rough slab being put into this frame, the pressure forces the body to spread out, so as to fill the enlargement at the base of the mould, then the surplus goes between the piston and the frame, that is, on to the face that does not show. To take them out of the mould the frame is raised, as shown at the left of the engraving, and the paving tile which remained on the bottom of the mould is taken out by hand.

This press, made by M. Pinette, can press 500 paving tiles an hour. The only disadvantage is that there is more pressure on the lower face of the paving tile, while the opposite would be better. Care must be taken to put the rough slab well on the surface of the mould, in such a way that no air bubbles can remain under it, as these would cause defects on the surface that shows. The same arrangement of moulds, naturally, can be adapted to all the presses that have been described already.

After being made, the paving tiles are generally put together two and two, with the visible faces in contact, and are put thus in the drying sheds. When they are thin ones care must be taken that they do not get out of shape; also, it is necessary to dry them in piles, the upper paving tile being covered with a burnt paving tile on which rests a brick or some kind of weight. This method has the disadvantage of making the

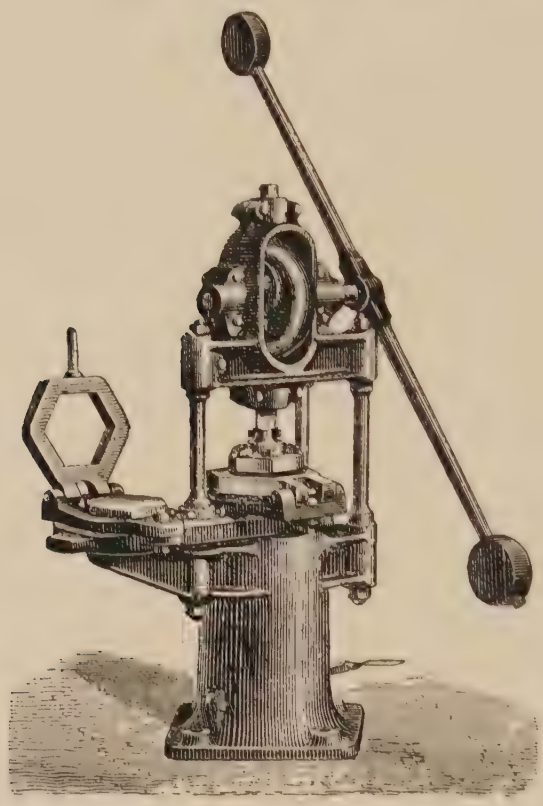

Fig. 265.—Press for Paving Tiles.

drying considerably slower, but it is absolutely necessary to employ it in order to obtain straight goods.

The paving tiles are burnt in all kilns that are used for tiles. Thick paving tiles can be charged in twos, as we have just said, by putting them in flat so as to leave spaces. Thin paving tiles ought to be piled up so as to prevent them warping, and the other goods charged at the same time in the kiln as the paving tiles should be placed in such a way as to

prevent these piles from tumbling over. It is necessary to have a smoking, very slowly and carefully, before the burning. If at the commencement of the slow firing there remain any traces of damp in the piles, there are formed round the paving tiles whitish blotches that are very ugly. In the same way the slow firing must be carried on very gently, to prevent the same thing from happening when the water of combination is being driven out. These precautions, that must be taken during the drying and burning, make the manufacture of paving tiles more difficult than that of any other terra cotta for building purposes. Ordinary paving tiles are usually made in tile works, and do not need any implements or special arrangements, except those that have just been mentioned.

## § 4. Pipes.

**222. Pipes for Gas Channels.**—The terra cotta pipes used on buildings are of two kinds: those intended for conveying gas and those intended for water courses.

The pipes for gas are used as chimneys and ventilators. They are of very varied shapes, the description of which belongs rather to the art of building than of pottery, because, whatever the arrangement employed, the methods of manufacture are the same. We will then describe the following types (Fig. 266) by way of example, without discussing the use of them or their respective merits. The round vents or flues, Type I., are round pipes with ridges at the two ends, from $5\frac{1}{8}$ to $9\frac{7}{8}$ inches in diameter and $11\frac{7}{8}$ to $19\frac{2}{3}$ inches in height.

The flues, Type II., are rectangular, with rounded corners, also for fitting together with ridges, the interior dimensions varying from 5 by 7 inches to $9\frac{7}{8}$ by $11\frac{7}{8}$ inches, with a height of $11\frac{7}{8}$ to $19\frac{2}{3}$ inches.

These two types of pipes can be placed in an independent manner, while the bonded flues, Type III., are built into the walls. They are made straight or sloping, or with projections to keep them together better.

Lastly, in some cases, by an idea of beauty that is perhaps only imaginary, the walls of them are made hollow, Type IV.,

in the hope of isolating them better. The body used for these pipes is the same as that used for making hollow bricks.

The moulding is done by squeezing them out in semi-soft body, with piston propellers, generally worked by hand. Fig.

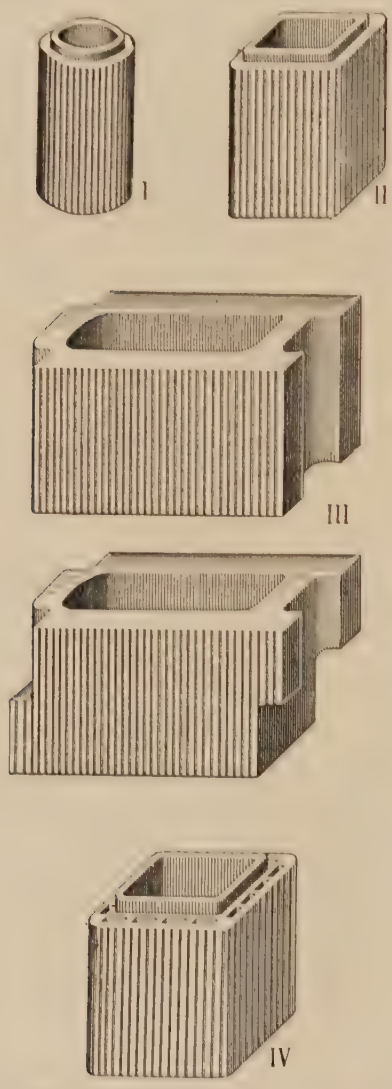


Fig. 266.—Types of Pipes for conveying Gas.

76 (page 200) shows a machine of this kind, made by M. Pinette. A metallic cylinder is filled with body, pressing it together as much as possible so as to prevent empty spaces being left, then the piston is set in motion by means of a crank. This piston

descends vertically and forces the body to pass out through a die plate below, arranged as shown in Fig. 69 (page 196).

The body when moulded rests on a balanced platform, which goes down with it. When the desired length is reached, the workman is warned by a noise: he leaves off turning the crank but keeps it in position, and a second workman slips along the frame, which is provided with a metal wire, and cuts off the cylinder of the body. The platform is leaned upon to make it go lower down, and the moulded pipe is taken away, resting on a little board, to be put into the drying shed. Lastly, by means of a pedal the platform is raised again and a second

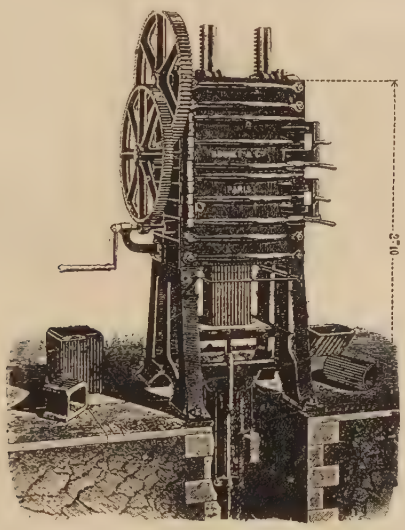

Fig. 267.—Machine for Pipes.

squeezing out is commenced. The moulding is thus carried on until there is no more body in the machine. Then the piston is raised, and, after refilling, the process is begun again.

During the time of stopping that is required for cutting them, it is absolutely necessary to keep the crank in place on account of the compressed air that there always is in the body of the cylinder, which would otherwise raise the piston and produce inequalities in the pressure, which would cause defects in the moulding.

Fig. 267 shows a machine of the same kind with a rectangular piston, in which the body is put in through a side door behind, and this is afterwards firmly closed up.

In order to increase the amount produced two cylinders can be used, turning round one of the uprights of the machine, as shown in Fig. 268; one of these cylinders is being loaded while the other is being worked (MM. Boulet et Cie).

The preceding machines can make from forty to eighty pipes an hour. In larger factories machines with continuous work-

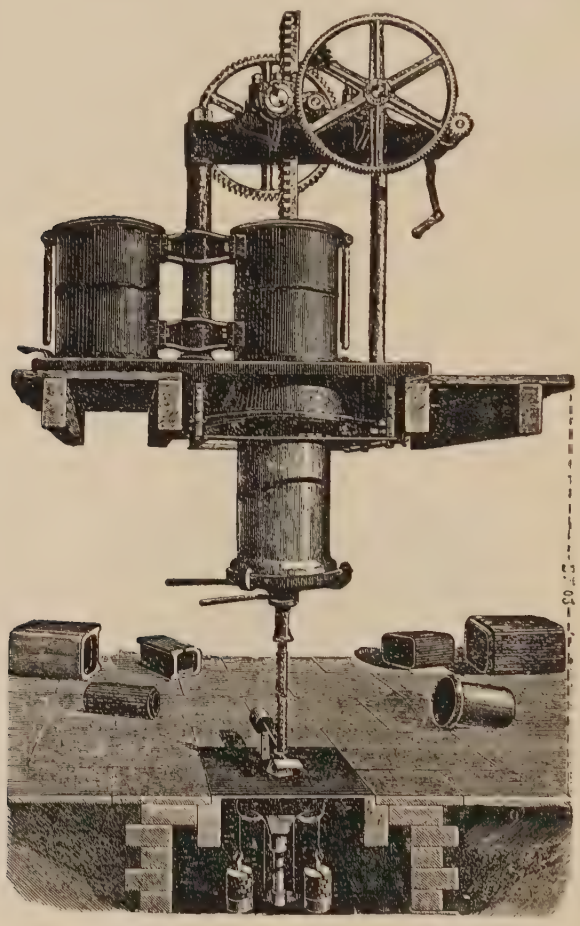

FIG. 268.—Machine for Pipes.

ing are made use of; these will be described *à propos* of moulding pipes in stoneware (Art. 278).

When sloping pipes have to be made, it is sufficient to incline the board on the platform, and to place the cutting frame in such a manner as to give it a position parallel to this inclination. To make the ridges, the body is allowed to

become hard; then a little strip of the outside body is taken out by hand, by means of a small cutting instrument that is passed round the pipe. Some time afterwards the pipe is turned over, and the same thing is done on the inside.

The baking of these pipes is done in brick or tile kilns. In the charging they are arranged vertically, by placing, if possible, two pipes of different sizes inside one another.

These are made in tile works, or even in brickfields. They do not, as a rule, present any difficulties. When the pipes are cracked or even broken they can be mended with plaster, and they profess that these mended pipes are afterwards more solid than the others.

**223. Pipes for Water Courses.**—The terra cotta pipes for carrying water were formerly very much used, but now they are almost entirely replaced by stoneware pipes, so we shall speak of them when talking of the manufacture of those wares, the process of moulding being the same. As to the burning of them, it is done in the same way as that of the preceding pipes. These terra cotta pipes are often glazed inside to make them watertight; the methods used for this purpose will be, as we said at the beginning of this chapter, discussed in Chapter XI. (Art. 247).

There is, however, a kind of pipe which cannot be made in stoneware, and about which it is advisable to say a few words; these are pipes for drainage. We know that these are simply cylinders of about 2·36 to 7·87 inches in diameter inside, and that they are put together by placing their ends in a piece of pipe of a larger size. They are made by being pressed out in machines similar to those used for hollow bricks. For this purpose die plates similar to those shown in Fig. 269 are used. For the large diameters only one pipe is made at a time, while for small sizes two, three, or even four can be made simultaneously. They are cut with the same cutting apparatus that is used for bricks. As to the burning, that is done in brick or tile kilns, by putting the smaller pipes in the larger ones, and piling them up so that their length is the same way as the current. This manufacture, which is a very easy one, is done in tile works or brickfields.

## § 5. Architectural Terra Cottas.

224. Besides bricks, tiles, paving tiles, and pipes of all kinds and sizes, numerous kinds of terra cottas are used in building that do not belong to these classes. Most of them are for a decorative purpose, and are made either from the current patterns belonging to the manufacturers, or according to the original designs of the architect or the decorator.

The bodies used in the manufacture of these architectural terra cottas ought to be plastic enough to lend themselves easily to moulding by hand. The preparation of them, which must be very carefully done, is best done in dry powder, if, as is almost always the case, the goods are required to properly resist the weather. It is equally necessary that the body should

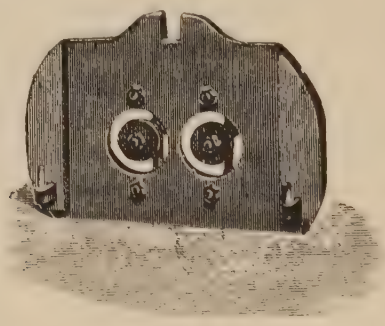

Fig. 269.—Draw Plate for Drainage Pipes.

be somewhat fine, that is to say, that the grains which it contains should not be coarse, for without that the ware would have a rough surface which would be filled with all the impurities of the air, and would quickly look disagreeably dirty.

In some cases moulding by expression or turning can be employed, but mostly moulding by hand in plaster moulds has to be resorted to. If the number of pieces to be made is very few, the expense of the moulds may considerably increase the cost price of these terra cottas. This method of making has been already described in the chapters devoted to moulding and decoration, with all the variations belonging to them. The general rules have also been given that one ought to try and follow in making the patterns (Art. 118) in order to obtain wares which will not be liable to warp or break. It is

advisable, however, to add that it is difficult in terra cotta to obtain long, straight pieces, as, for example, the handrails of balustrades; hence it is better to make smaller pieces and have more joints.

The drying is done in the moulding shop or in an adjoining drying shed, so that the drying can easily be overlooked by the moulder.

The burning is done in the kilns used for tiles or paving tiles by protecting the architectural terra cottas from the flames by means of other less delicate goods. Muffle kilns are also used sometimes, although in that case there is a danger that the temperature for burning them will not be high enough. In factories devoted entirely to making architectural terra cotta it seems best to use round kilns with descending flames.

Architectural terra cottas are decorated either by their shape or colour. Concerning the former, there is nothing to be added to what has been already said; on the other hand, the colouring needs additional explanation.

Mostly, a single piece has to have a nearly definite uniform colour. When this colour varies from pale yellow to orange, red and reddish-brown, it is obtained by mixing the clays, following the directions given in Art. 147 as to the different colours produced by oxide of iron. White colour, or rather yellowish-white, requires the use of white refractory clays, made suitably thinner with white sand or cement, with the addition of a certain proportion of marl, so as to give the body some lime as a flux. Alkalies can also be used, naturally, but the price of them is considerably higher. But the scraps of window glass can be used with advantage.

The use of fluxes is indispensable, in order to lower the temperature at which they are burnt, and to obtain goods which will resist the weather. The proportion of them must be such that a hard, well-burnt body can be obtained between 1,000° and 1,200° C.; below that there is a risk of the carbonate of lime not being entirely decomposed, and above that, the traces of oxide of iron, which all clayey bodies must necessarily contain, will give them a brighter colour the higher the temperature is. Some special pottery manufacturers produce a kind of

terra cotta which imitates perfectly the natural calcareous stones.

There have been used also, in making ware in imitation of stone, some white sands, with the addition of alkalies, like those used for polishing glass, and which are the waste from the manufacture of glass. The disadvantage of these sands, which, however, give beautiful and good ware, is their want of plasticity, which necessitates their being moulded in powerful presses, usually with hydraulic power.

Lastly, the bodies of a grey or black colour can be obtained by burning them in a very reducing atmosphere, using the methods already described *à propos* of black tiles (Art. 220). When the cost price is not against it, the bodies can also be coloured with colouring oxides. The only oxides used are those of iron and manganese. The former are furnished by earthy ochres or certain iron ores, the latter by the ores of manganese that have been more or less washed. It is only a very exceptional thing, with bodies that are very slightly coloured, that oxide of cobalt can be added to give the blue shades. The colours thus obtained were discussed in Art. 189.

When, for reasons of economy, or on account of certain difficulties of manufacture, the desired colour cannot be given to the body, then slips must be resorted to. The composition and application of them have already been discussed (Arts. 114 and 190). In order to obtain a perfect agreement between the body and the slip, there must be put into the latter as large a proportion as possible of the body itself. Thus slips with more colour than the body can easily be produced. On the other hand, the light shades, and white in particular, are much more difficult of application. The white clays, which then have to be mixed together, make the slip much more refractory, and calcareous or alkaline fluxes must be added to it. The white slip in particular, which always requires rather a high temperature for burning it, can only be applied to bodies which are relatively only slightly fusible. It is seldom that it can be used without the composition of the body itself being modified.

The application of these slips is either with a brush on the ware when nearly dry, or by the method of making by in-

crustation, described in Art. 114. The processes of drying and burning have been already mentioned; it is sufficient to add that white slips must not be placed by the side of coloured bodies or slips. In fact, there is always a certain volatilisation of the oxide of iron, which would soil the white bodies.

Architectural terra cottas, instead of having a uniform colour, can also be of different shades. Naturally, for this purpose, slips of different colours can be made use of. We must, however, observe that, except for certain wares with distinctly marked different reliefs of plane, this method of decoration gives hard tones, that are not very satisfactory in appearance. Usually, it is better not to put different colours by the side of each other, but only to try and shade the natural colour of the body. In that case decoration by impregnation can be used advantageously (Art. 189), by using either a very light slip, or simply some of the colouring matter diluted with water. It is applied with a brush in successive layers. This method can produce very remarkable effects by lightening, for example, the parts that are in relief and by darkening the sunk parts.

## § 6. Vases, Statues and Decorative Objects.

**225.** The manufacture of decorative objects in terra cotta dates from great antiquity. We see in the history of pottery that the Greeks especially, by the purity of the shapes and the finish of the decoration, attained perfection. This beautiful manufacture disappeared after the fourth century, to give place to coarse ware without any artistic value. The introduction of faience during the Renaissance turned the potters away from terra cotta, and it was only from the nineteenth century that decorative objects of this kind were manufactured again.

At the present time vases, statues, jardinières, flower-pot stands, and all other terra cotta objects that are used for decorating dwellings are manufactured by processes similar to those that have just been described for architectural terra cottas. The bodies employed are, however, finer, the clays are always washed, and the sands which are used to open them must be very fine, so as to give the ware a smooth and even polished look.

They are made by turning or moulding by hand in plaster moulds. For statues they must necessarily be moulded in several pieces, which are afterwards stuck or joined together, because we must not forget that all the thicker parts, such as the trunk, the head, etc., ought to be hollow. The joining together of the parts is a somewhat delicate operation if the model is to be reproduced exactly. It very often happens that the position of certain parts, such as arms or legs, is not noticed exactly, a defect which takes away a great deal from the artistic value of these goods. Besides, the moulders frequently have the bad habit of touching up to round off the contours, which results in the reproductions being finished in undecided forms that have lost all the character of the original.

The drying is done in the moulding shop, and the burning usually in a muffle or in saggers.

These terra cotta wares are made in some tile works and potteries. There are also some special works for them, particularly in large centres of consumption.

Concerning the decoration chiefly resulting from the forming of them, we need only refer to what was said on this subject in Art. 188. Great importance is also attached to this, that when the piece is to be of one colour, that colour should be uniform. The same as in architectural terra cottas, by using suitable clays wares of a yellowish white, yellow, pink, orange or red can be obtained. For grey or brown colours oxide of manganese is mixed with the body. In this case it is not wise to burn them in a reducing atmosphere, especially if it is to be done in a muffle.

This uniformity of tint needs a careful manufacture, and especially a very regular burning. It frequently happens that, in order to keep these terra cottas a beautiful shade, they can only be burnt at a very low temperature. This is not a disadvantage if the goods are kept inside buildings, but they cannot be exposed out of doors without being quickly spoilt.

It is easier to get this uniform tint by putting over the ware, when made, a slight slip, made of the body diluted with water. Some manufacturers get rid of all these difficulties by simply painting the burnt ware with water colours or with a

size. This process, which takes away all ceramic value from the ware, is, besides, easily recognised by the traces of colour that comes off when rubbed with the finger or with a damp cloth.

Ware of many colours is easily obtained by means of coloured slips. These slips can be thick enough to allow of different designs being made with a brush: for example, ornaments, flowers, figures, standing out in white on a coloured ground. This is the process known as barbotine painting (Art. 190). Very diluted slips can also be used; these are also put on with a brush, in successive layers, so as to form shades. Thus more relief can be given to the model, by darkening the lower parts and lightening the projections, or even by covering with different light tints, the various parts of the ware. This latter method has latterly been very much used for decorating statues.

## § 7. Common Pottery.

**226.** These wares are the most ancient that were made, except perhaps in Egypt. As we said in the historical summary of the potter's art, they are found among all nations at the commencement of their civilisation. Until the middle of the Middle Ages they were almost exclusively used for all domestic purposes. Glazed ware, then faience with lead glazes, and finally faience of a fine body, stoneware and porcelain have completely taken their place, except for some special purposes, and these are becoming fewer every day. This branch of the potter's industry, then, was formerly much more developed than in the present day. The potters were among all nations one of the most important guilds and often enjoyed special privileges. At the present time the small pottery works which drag miserably along can only be considered as a relic of a state of things that has disappeared for ever. The few common wares in terra cotta which are still used have usually become only a secondary article of manufacture in tile works and in some faience works.

The body that was formerly used had to be made of a fine, fusible clay, which was mixed, when necessary, with an equally fine sand. When a suitable clay could not be found mixing was resorted to. The preparation consisted in treading and

kneading. The body, which was always rather soft, was built up either by hand, without moulds, by using pellets for large pieces, or else by turning, the last finishing consisting of cutting the ware by means of a templet. Lastly, the burning was done in horizontal kilns with a single fireplace, or else in square kilns with ascending flames, which naturally were heated by wood.

The moulding of these ancient objects was often very remarkable on account of the considerable size of the pieces, as it was remarked when on the subject of jars or amphora (Art. 10). On the other hand, the burning often left much to be desired. It seems that the ancient potters found serious difficulties in the way of getting a high enough temperature; they also used very fusible clays, especially calcareous ones, whence the name of potter's clay, which has been given to a kind of ferruginous calcareous clay, still mentioned by certain authors as being necessarily used as a foundation in the manufacture of this class of ware.

At the present time the bodies employed are the same as those that are used for making tiles. These bodies, after being prepared in the way already described, are kept in a heap in the shape of blocks in the moulding shops of the potteries.

The method of moulding naturally depends on the shape of the objects. For household utensils, which are usually round, turning is used; this is sometimes made more accurate by means of a templet. The handles, spouts and feet are put on by sticking. Flower-pots are also almost always turned. They can also be made by moulding on the jolley (Fig. 100, page 219), though this method needs a considerable number of moulds. Lastly, they can be done by moulding in a press, as shown in Fig. 102 (page 222). In that case it is wise, before taking them out of the mould, to give a certain rotatory motion to the chuck, so that it may spring away from the piece which ought to remain in the mould. With this machine fifteen pots of medium size can be made per minute.

The wares of this class being always thin and relatively light, they are easily dried in the moulding shop or on the stages placed close by.

If the factory has continuous kilns, the burning can be done without any difficulty; nevertheless they must be charged in such a way as to protect them, by means of coarser ware, from contact with the flames or ashes. If a special kiln is desirable, it will be enough, when the output is always small, to use a small round kiln with descending flames.

When the ware has to be exposed to the weather, it is necessary to burn it at a rather high temperature, and to follow the directions which will be given on the subject of experiments in terra cotta.

## § 8. Pottery for Water and Filters.

**227.** These wares have been made for a very long time in all southern countries for cooling liquids. On account of their porosity the liquid oozes out on to the surface of them, and if they are carefully put into a current of air a quick evaporation takes place, which lowers the temperature by from 5° to 8°. They are also sometimes used as filters.

The body used is the same as that used for ordinary ware, only different methods are used to render it more porous. If the clay used is sufficiently plastic it will be sufficient, as a rule, to add sand to it, or, better still, some grog of burnt earth, and to heat it at a comparatively low temperature, which has no disadvantage in the use that is made of these wares. The same method can also be used that was described for light bricks (page 501), but then the combustible materials that were added to the body must be reduced to a powder, or else the air-holes produced would be too large, and the liquid would run out and not ooze out. Lastly, sometimes salt in rather fine grains is added to the body. At the temperature at which it is burnt, and which is always low, this salt remains undecomposed, and it is dissolved afterwards by putting the water bottles into water.

The same porous body can be employed as a filter for clarifying liquids, and especially water. For this purpose, for some time now, there have also been used white bodies with kaolin, similar to the bodies for porcelain, but which, being simply burnt at a very low temperature, are really terra cottas.

The manufacture of these wares does not present any difficulties.

## § 9. Tobacco Pipes.

228. There are two kinds of tobacco pipes: one kind, made in a single piece, composed of pipe and bowl, is used in Northern and Western Europe; the other, in two pieces, the bowl only being of terra cotta, is used in the countries bordering on the Danube and in the East.

For the first ones pure clays or fireclays are used, which contain so little oxide of iron that when slightly burnt they are of a white colour. In some factories clays that contain a little iron are also used, but the colour is discharged by the presence of a certain quantity of lime. These clays are fine

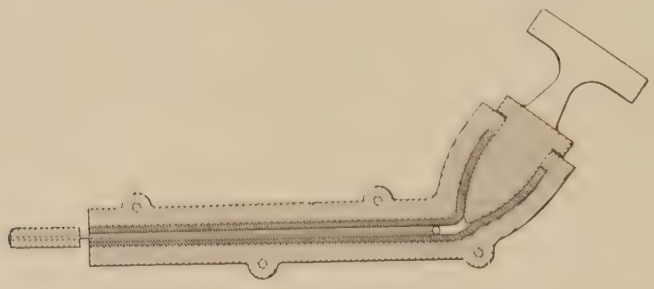

Fig. 270.—Moulding of Tobacco Pipes.

enough not to need to be washed. They are sorted by hand, and this is followed by a preparation in a pasty state, usually by hand, which must be somewhat carefully done, so as to make a very homogeneous mass.

They are fashioned by being moulded by hand. To begin with, a little roll of body is made, to which is attached at one end a little lump of body. By means of a needle, terminated in a little ball, a hole is pierced down the middle of the roll; then, when this rough model is stiffened, the whole is placed in a copper mould in two parts (Fig. 270), which are pressed together by a screw. Then, to form the bowl, a chuck is put in similar to the key of a stop-cock, at the same time giving it a rotary motion. After the chuck is taken out, the piercing of the communication between the bowl and the pipe must be finished, by means of a point that is put in through the bowl;

then the pipe is taken out of the mould. This moulding, which is very simple, is usually done by women or children, who become very quick at it.

Naturally, all the ornamentation desired can be got in the mould, provided it will prove no hindrance to the pipe being got out of the mould. If such is not the case, then it must be stuck on afterwards. Very good pipes are afterwards polished on the outer surface.

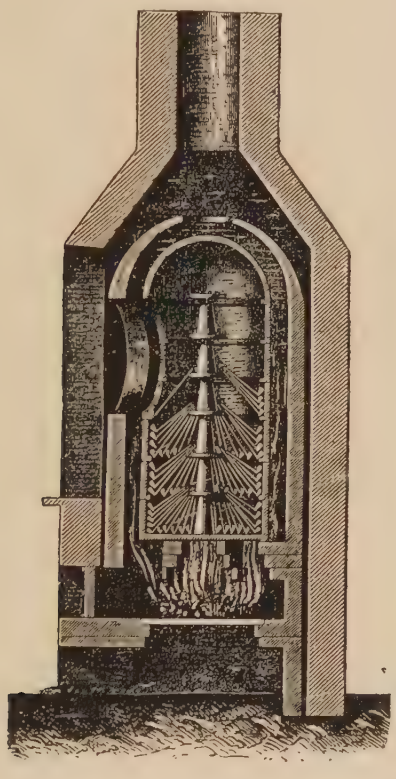

Fig. 271.—Burning of Tobacco Pipes.

Pipes must be dried very slowly on account of the great plasticity of the body, but there are no difficulties connected with it.

They are burnt either in small square or round kilns with ascending flames when charged in saggers, or else in muffle kilns. Fig. 271 shows an arrangement of this description, with the special method of charging.

In pipes made in two pieces the bowl is, on the contrary,

made of a plastic ferruginous clay similar to that used for making fine red paving tiles, of which we shall speak further on. When necessary, it is thinned with grog of the same clay.

The bowls are made by being thrown on the wheel and finished off by being turned, then the part for fixing the pipe in is stuck on, as it has been turned separately. They are burnt in saggers, but on account of the simpler shape of the pieces they do not need a special method of charging.

To finish tobacco pipes needs a number of different operations, either intended to make the end that is put between the lips less porous or to polish them, or else to ornament them; these operations are of no interest from a potter's point of view, but are very much appreciated by smokers.

On account of the dexterity that is required for making tobacco pipes, which can only be acquired by a long apprenticeship, the manufacture of them is localised in a certain number of places, where there is a population of workpeople who are accustomed from childhood to this work. The most important centres of this manufacture are: In France—Saint-Omer, Arras, Nîmes, Marseilles; in England—London, Broseley; in Germany—Cologne, Aix-la-Chapelle, Hanover; in Holland—Gouda; in Hungary—Debreczen.

## § 10. Lustre Ware.

**229.** Lustre ware was manufactured by the Egyptians, the Greeks, and the Romans from the sixth century before our era till towards the year 300, a time at which it fell completely into oblivion. It was only in the course of the nineteenth century that certain potters succeeded in making imitations of these ancient wares. The Greeks, in their colonies of Southern Italy, had arrived at perfection; their wares, called Campanian, are the glory of museums, but since then pottery has followed other lines. The porosity of the body used in lustre ware causes it now to be rejected by the poorest peasant, and to the fine, sober, severe decoration of the Greeks is preferred the brightness and relief of modern glazes. Also the manufacture of lustre ware at the present time only consists

of an archæological imitation, so to speak, of the ancient models.

The body is made with a clay, sometimes moderately plastic and ferruginous calcareous (Greeks and Romans), sometimes decidedly silicious (Egyptians). The ware was made by turning, and this was followed by the important work of finishing. The burning, which is usually at a low temperature, was sometimes oxidising, giving products of a colour varying from yellow to bright red; sometimes reducing, then making the body of a more or less deep grey tint. As to the lustres which have been used for covering these wares, the composition of them remained a secret for a long time, and now the problem cannot be considered to be entirely solved.

In order to understand the processes employed in the manufacture of lustre ware, we must first notice that the Greeks understood slips, which allowed them to make white, yellow, or deep red ornament by means of mixtures of white clays and ochres. In the second place, it is important to notice that they used frequently to polish the ware before it was burnt, an operation that has the effect of giving to the surfaces a particular brightness after it is burnt. These methods of decoration, added to the action of fusible ashes from the wood which was used as fuel, have often led people to think that some of their wares were covered over with a glaze.

However, by examining closely the ancient lustre ware, it may be noticed that certain red and black or grey parts in the Greek ware, and the more or less greenish parts in the Egyptian ware, must have been decorated by means of a thin layer of a somewhat vitrifiable material, which was probably put on with a brush. According to the analysis made under the direction of Brongniart, this lustre is an alkaline silicate, the very thin layer of which when burning combines with the elements of the body. When it was red it contained oxide of iron, from which the colour was added to the body. The green shades of Egyptian pottery were produced by oxide of copper. As to black lustre, which was so remarkable, there the analysis has only found oxide of iron, sometimes mixed with a little oxide of manganese, but in a proportion that is insufficient in

an ordinary way to produce a black colour. On the other hand, this lustre, when heated again in an oxidising atmosphere, becomes red. This experiment shows that the black colour must be attributed only to being burnt in a decidedly reducing fire. As in many wares the background is black, while the places where the ornament comes off are red; either spaces have been left, or else the black lustre has been scraped off afterwards.

Besides, we must take into account that the Greeks would not have the same ideas about pottery as we have, and that they would not consider a ware as finished when it came out of the kiln. On account of the soft nature of the body, they could polish it, even carve it, and then paint or varnish it.

As to the composition of the lustres, it is still doubtful, on account of their uniting inside with the body, which prevents them from being taken off and analysed separately. If the following composition, which was given by Salvetat for a black lustre, be admitted:

| | |
|---|---|
| Silica | 46·30 |
| Alumina | 11·90 |
| Oxide of iron | 16·70 |
| Lime | 5·70 |
| Magnesia | 2·30 |
| Alkalies | 17·10 |

then we see that it is composed probably of sand, of alkalies, furnished either by the ashes or by volcanic productions, and of a ferruginous earth. Only when burnt in a decidedly reducing fire can it attain a black colour.

## § 11. Properties and Tests for Terra Cottas.

**230. Causes of Disaggregation and the Remedies.**—All terra cottas when well manufactured ought to be able to resist indefinitely the action of the weather, and the mechanical effects to which they are subjected in building.

If a partial or entire disaggregation of a terra cotta is noticed, the causes that may have produced it are the following:—

1. External physical causes: damp, vegetation, ice, saline atmosphere.

2. Mechanical causes, inducing it to crack, breaking it by bending or by external pressure.

3. Internal chemical causes: the presence in the terra cotta of lime or magnesia and soluble salts.

The examination of these causes of disaggregation allows us to decide what is the original fault in the terra cotta, and consequently to show the methods to be used so as to avoid it.

When the terra cottas are too friable, a prolonged damp or frequent rains are sufficient to crumble it away. Under these conditions they may also be covered with vegetation, the roots of which will help to destroy them. This defect, which is not very frequent, arises from the use of bodies that are too sandy or insufficiently burnt.

Frost has a more powerful and more dangerous action. In consequence of a lowering of the temperature, the water, which was absorbed already by the terra cotta, solidifies in the interior of the pores. The increase in volume of ice at the moment of freezing creates internal tension, which may make the surface crack, then gradually crumble away. The saline atmosphere of the seaside exerts a similar action; this must be attributed to the formation of salt crystals inside the pores, which act in the same way as ice does.

It must be observed that it is not the intensity of the cold that is to be feared, but a cold of only 2° or 3° below zero following quickly on a rainy season, because then the water contained in the pores of the terra cotta has not had time to evaporate. There is nothing to be feared from cold, however intense it may be, that follows a dry season. On the other hand, snow may very effectually protect the covering. These remarks explain why it is that some terra cottas, which perfectly resist severe climates, can be crumbled away in temperate, but damp countries.

In order that a terra cotta should resist the action of frost it is necessary—

1. That the walls of the pores should have a sufficient tenacity to bear the pressure of ice; this can be obtained by using bodies which are sufficiently plastic, and especially by burning them at a somewhat high temperature.

2. That the pores should be uniformly spread over the whole mass, that is to say, that the latter should be homogeneous without planes of cleavage or of thin layers. This condition is naturally fulfilled when a very homogeneous body is used and when it is moulded by hand, either in a mould or on a wheel. On the other hand, expression and press work always have a tendency to give a lamellar structure to the body. In that case, the water, instead of being enclosed in a number of small cells and causing there, when the frost comes, the tensions that balance each other, is found in the shape of a sheet between the different leaves, and exerts, by being changed into ice, a pressure which, by not being balanced, may cause these layers to crack. This lamellar structure is so much the more noticeable when the moulding is done with a stiff body, as, the plasticity being less, the layers cannot join together. In press work with a dry body, this primal cause of thin layers is decidedly aggravated by the air being enclosed in the mass, which remains imprisoned at the time of pressure, and forms layers that destroy all cohesion between the different leaves.

The methods for obtaining terra cotta that is absolutely impervious to frost are the following:—

1. A thorough mingling of the raw materials, in such a way that thin and rich parts cannot be found in the body, which would slide on one another when being moulded, without mixing together, thus causing a lamellar structure.

2. Moulding with a body the consistency of which is as nearly as possible like that used for moulding by hand.

3. The employment for moulding of processes and machines which reduce to a minimum the lamellar structure of the body to be moulded.

4. When the last two conditions cannot be fulfilled, it is then necessary to raise the temperature for the burning process sufficiently to cause the fluxes in the mass to begin to vitrify. If this raising of the temperature cannot be done without causing the ware to get out of shape, the only alternative is to modify the composition of the body.

In a general way we may say that moulding by expression or by presses, with firm or dry bodies, can only produce ware

that is impervious to frost on condition that it is burnt at the temperature just mentioned.

The mechanical causes which may account for the breaking of terra cottas are the following:—

For *bricks* it is the weight they have to bear that may cause them to be crushed. Except under certain exceptional circumstances, the resistance of masonry when of bricks is limited by that of the mortar that is used in the joints. It is only bricks made of very sandy bodies, and too slightly burnt, that can be crushed under ordinary circumstances in building. If very resisting bricks are wanted, plastic bodies must be employed, they must be moulded at a comparatively stiff consistency, without repressing them, and be burnt at as high a temperature as possible. The resistance to crushing per square inch of bricks is, in fact, as much greater as they are denser. Yet, except in some special cases, it is unnecessary to try and obtain great resistance, which can only be had at the expense of other qualities.

For *tiles*, the greatest strain they have to bear is the weight of a man moving about on the roof. This would be a weight of two hundredweight placed in the middle of them, and trying to break them by bending them when they are put on, as they ought to be, overlapping, that is by reckoning on the separation of the fitting together or of the overlapping. As their thickness can be modified, it is always possible, with a certain body and method of moulding, to make tiles sufficiently resistant.

For *paving tiles* it is advisable to test them for wear, and for *pipes* for the resistance to an internal hydraulic pressure.

In these two cases the greatest resistance is also obtained with plastic bodies, close and well burnt.

It is also interesting to take into account another mechanical cause of breakage that is common to all terra cottas, that is the shocks that they may receive during transport, or while they are being placed. From this point of view, the bodies that work best are also those that are most plastic, but it is advisable not to carry the burning to the point of vitrification, because when they have attained the highest point of resistance

by a suitable amount of heat, if heated above that point the terra cottas become more brittle.

Lastly, terra cottas may crumble when they contain lime or caustic magnesia, which, by afterwards becoming soaked, increases in volume and acts like frost does. We have seen how by a better preparation of the body this may be avoided. Yet, if the expenses caused by a more careful working of the body were too great relatively to the small value of the ware produced, the harmful action of the lime could be lessened by dipping the terra cottas when they come out of the kiln.

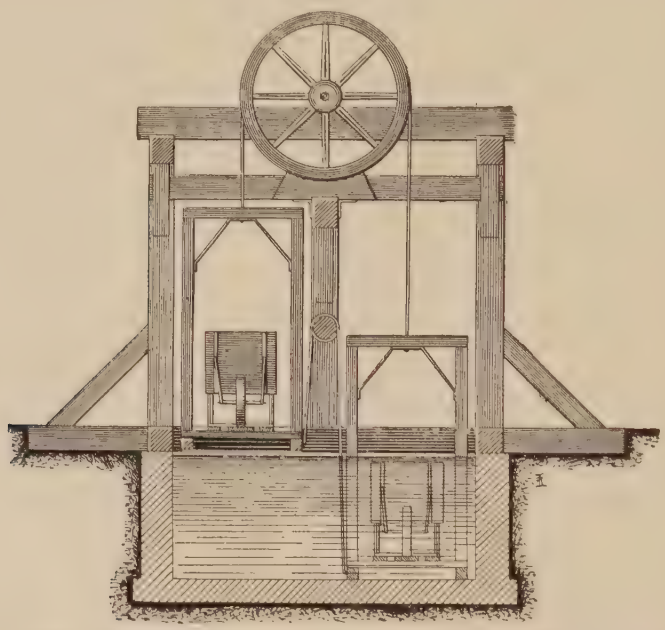

Fig. 272.—An Apparatus for Neutralising the Action of Lime and Magnesia.

For this purpose the apparatus shown in Fig. 272 can be used; this consists of an underground pit full of water, into which are lowered barrows loaded with goods. It would seem, in this case, that the lime or magnesia are diluted in the large quantity of water, instead of swelling where they are, as they do when only made damp.

When the bodies contain a large proportion of soluble salts these can be dissolved by rain or damp and become crystallised in the pores on the surface, acting in the same way as the saline atmosphere of the seaside. This action is, however,

rare, and usually the efflorescence of the soluble salts only has the effect of soiling the surface, and of making the parts that are above them scale off. This defect can be avoided by washing the bodies, or by burning them at a temperature sufficiently high to cause the combination of these salts into insoluble compounds. The processes of chemically purifying the bodies which can also sometimes be employed have been already specified (Art. 82).

**231. Methods of Testing Terra Cottas.**—The methods of testing terra cottas were the subject of resolutions discussed at the Conferences of Munich (1884), Dresden (1886), Berlin (1890). More recently (1895) they were decided by the Commission on the Methods of Testing Building Materials appointed by the French Government. We cannot do better than reprint, with some remarks, the conclusions arrived at by this Commission, according to a report presented by M. Debray, General Secretary to the Commission, and by the author of this work:—

*Samples.*

The tests for terra cottas should always be made on the market goods.

If it is desirable to know very exactly the value of a manufacture it is advisable to work with samples at various degrees of burning. Often it is sufficient to examine the samples which are least burnt, which will be easily recognised by the look, and more especially by the hardness being less and the dimensions slightly greater than the average.

*General Directions.*

The commercial mark of the samples will be indicated, their form, the state of their edges and surfaces, as well as their colour.

For bricks and paving tiles the dimensions will be measured as to length, breadth and thickness. In tiles the length and breadth will be measured, and sketches or sections will be made, enough to show in a clear way the hollows and projections, as well as the methods of fitting together, that the samples may have. Lastly, for pipes the interior diameter will be measured, the usual length of the pipe, exclusive of the fitting part, the

thickness of the walls, as well as the form and arrangements for fitting them together, if there are any.

For bricks and tiles the dimensions will be verified, as in the same piece these ought to be identical; the difference will be indicated if it is more than 1 per cent.

When the test laboratory has at its disposal a sufficient number of samples of the same production, it will be useful, on the one hand, to measure the most burnt or the smallest ones, and, on the other hand, the least burnt or the largest ones. The differences observed, when there are any, will be indicated.

### *Physical Tests.*

#### 1. *Observation of the Structure or Homogeneousness.*

The observation of the structure or homogeneousness will consist of the examination of a fracture, made either by eye or with a magnifying glass.

It will be advisable to make a note—

(*a*) Of the look of the fracture, whether granulated and in more or less noticeable roughness, or smooth, or with a conchoidal surface.

(*b*) Of the coarseness of the grain, marking, according to the classification adopted for stones of a natural construction,[1] whether the grain is fine, medium, or coarse, and whether the grains are uniform or of different sizes.

(*c*) Of the homogeneousness, by observing whether the mass is entirely, moderately, or slightly homogeneous, whether there are any planes of cleavage or scaling, whether they are more or less numerous and more or less pronounced.

#### 2. *Specific Weight.*[2]

The determination of the specific weight of the material will be made from the powder produced from pieces ground up until they will pass through a sieve of 900 meshes.

[1] Very fine grains (0·2 millimetre to 0·4 millimetre), fine grains (0·3 millimetre to 0·8 millimetre), rather fine grains (0·5 millimetre to 1·2 millimetre), medium grains (1 millimetre to 2·5 millimetres), slightly coarse grains (2 millimetres to 4 millimetres), coarse grains (3 to 7 millimetres), very coarse grains (5 millimetres and over).

[2] The determination of the specific weight is of no interest from the point of view of the quality of terra cottas; it is only used for calculating the absolute porosity.

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The powder will be dried at a temperature of + 110°.

The determination of the specific weight will be by means of volumetres, by one of the methods in use at the present time, in such a way as to obtain the first decimal exactly, and the second approximately to two points.

The liquid used will be benzine or mineral spirit.

The temperature ought to remain constant during the whole time of the operation; it ought not to be above + 15° C.

### 3. *Apparent Density.*

The determination of the apparent density ought to be made as much as possible, with the samples that are whole, after being dried at a temperature of + 30° to + 40° C.

When the samples are of a regular geometrical form, allowing of the volume being determined by measurement, an ordinary metre rule is used having the marks down to the tenth of a millimetre; the weight will be determined by means of a scale, sensitive to half a centigramme.

When the samples are irregular in form, or have any receding angles, the volume will be determined, and consequently the apparent density, by means of the difference in weight of the sample in the air and in water. Care must be taken to first cover the surface with a varnish to prevent the water getting in. A thin layer of melted tallow put on with a brush and spread about with the finger answers this purpose very well.

### 4. *Absolute Porosity.*

The absolute porosity will be calculated from the difference between the specific weight and the apparent density.

### 5. *Relative Porosity or the Weight of Water absorbed in a Given Time.*

The determination of the weight of water absorbed should be made on a series of at least three samples, previously dried, either in the open air or in an oven, at a temperature of + 30 to + 40° C. It is advisable to work, as much as possible, with whole samples, and not with broken pieces.

After they have been dried the samples are put into water up to half their thickness for twelve hours, then put completely under water for twelve hours, thirty-six hours, seven days or twenty-eight days.[1]

If the samples contain a decided proportion of lime, magnesia or soluble salts, it would be wise to begin the experiment over again once or twice on the same samples.

The quantity of water absorbed, or the relative porosity, should always be calculated by volume, but the percentage of water by weight should also be indicated.

*Special Arrangements for Tiles.*—As to what concerns tiles, the Committee express the view that, as for roofing slates, a study be made of what will be the quantity of water absorbed per square metre of tiles when fixed, as they usually are in practice, on a frame with the least slope used for roofs, by submitting this frame to a regular rain of a definite intensity for a given time.

### 6. *Permeability.*

*Tiles.*—The test should be made with at least three whole tiles previously immersed for forty-eight hours, as described in paragraph 5. They should fix with pure cement, towards the middle of the upper face of each tile, placed horizontally, a glass tube, of about 1·278 inches interior diameter and 4·33 inches high. The tube, closed at the upper part by an india-rubber stopper, is put in communication with a reservoir giving a weight of 3·9 inches of water.

The water which can pass through each tile is collected in a reservoir placed under the lower face.

The permeability will be determined by the volume of water that has run through in an hour, after the experiment has lasted twenty-four hours.

[1] In the case when the time of immersion passes forty-eight hours, if the length of experiment is wanted to be shortened, the process of imbibition by the help of a pneumatic bell can be used, as described in the tests on the natural construction of stones. (Note of the Commission.)

### 7. *Tests for the Resistance to Frost.*[1]

The trials for resistance to frost ought, as much as possible, to be carried on with whole goods. The tests could, however, be made on broken pieces. In that case the cut or broken parts of the trials ought to be protected by a varnish or thin layer of tallow, with the object of not allowing the water to penetrate during the immersion except through the faces of the samples that are usually visible.

The tests for a normal resistance of frost, carried out as we have described for natural stones,[2] comprise :—

(*a*) The examination of the samples with the aid of a magnifying glass, by trying to notice whether cracks or splits are caused in those samples submitted to the action of successive freezings and thawings, repeated up to twenty-five times.

(*b*) The determination of the loss in weight of the frozen samples.[3]

[1] In our opinion, great reservations must be made on the subject of this method, the only one at present in use, but so far removed from the actual conditions of practice that it seems to us that it is not possible to draw any conclusions from the results obtained.

[2] In carrying out these tests the following details must be observed :—

(*a*) Distilled water must be used for the immersion, taken at the temperature of + 15° to + 20° C., or if distilled water cannot be had, then drinking water, taken at the same temperature, which has no disadvantages when the quantity of soluble salts need not be determined.

(*b*) The samples will be exposed to a temperature of – 15° to – 20° C.

(*c*) The length of exposure to the cold will be four hours.

(*d*) The thawing will be done by the complete immersion of each sample into distilled or drinking water at a temperature of + 15° to + 20° C. (For natural stones a volume of 500 cubic centimetres of water is suggested for a cubic example with sides of 7 centimetres length.) For dried samples in the state of imbibition after being immersed for twenty-four hours, the thawing is accomplished in damp air and not in water. In the interval which separates the successive freezings and thawings the samples are kept in closed cases, to prevent too large a loss of the water absorbed; further, care is taken, before submitting them again to the action of the cold, to plunge them for some moments into water, so as to keep them, during the whole period of the test, at the same degree of saturation as they had at the commencement of the experiment.

[3] If the samples have borne without deterioration the tests for resistance to frost,the resistance to compression and to bending of these samples must be compared, when they are dried again, with that of samples of the same production subjected to the same tests when dried, but without having been subjected to the action of frost. (Note by the Commission.)

For these tests must be used at least—

Three examples soaked with water by being immersed for twenty-four hours.

Three examples soaked with water until saturated.

### *Mechanical Tests.*

#### 1. *Resistance to being Broken by Crushing.*

*Bricks and Similar Materials.*—The test for resisting the breaking by being crushed should be made on pieces as nearly cubical in form as possible, obtained with ordinary bricks, for example, by putting two half bricks on one another, and joining them together with a thin layer of paste of pure Portland cement.

The surfaces to be compressed will be made exactly parallel by a covering made of a layer of the same body.

As for natural stones, the tests for resisting crushing can be made by means of apparatus with levers, or by means of hydraulic presses.

The test pieces ought to be placed between the pressing plates, covered over with a leaf of thin cardboard; it is best for one of the two pressing plates to be movable in all directions.

The dimensions of the bearing surfaces will be indicated in the official report of the test at the same time as the resistance in relation to the square centimetre of the carrying surface.

The test will be carried out on at least three test pieces of the same sample.

The mean of the results furnished will be calculated.

It will be wise for the test to be made on two series of test pieces, one in a dried state, the other in a soaked condition, while marking the degree of saturation.

#### 2. *Resistance to Breaking by Bending.*

*Bricks.*—The tests for resisting breaking by being bent will be made, for ordinary bricks, on the whole goods placed on two knives 7·87 inches apart, and loaded in the middle continuously until they break.

The rough weight which determines the breaking of each test piece will be indicated.

The goods, which are longer than ordinary bricks (flooring bricks), may be tested with a support, between the two edges on which they rest, equal to the support which they would have in use.

*Tiles.*—The tests for resistance to breaking by being bent will be made on whole tiles placed on two knives, and loaded in the middle continuously until they break.

When the tiles have not a rectilineal profile, little transverse horizontal bars of pure Portland cement should be put in, ·39 inch wide, at right angles to the supports and the medial knife, for the purpose of levelling the undulations and of making the action uniform over all the width.

One of these bars will be placed at the point where in the roof the tile ought to lean on the edge, and the other at the place where it rests on the lower tile.

The load that would have caused it to break will be indicated.

It will be wise to make the test on tiles soaked with water, marking the amount of saturation.

### 3. *Resistance to being worn by Rubbing.*

The determination of the resistance to wear from being rubbed will be made under the same conditions as for natural stones,[1] as far as it concerns the dimensions of the test pieces in the testing properly so called.

[1] For determining the resistance to the wear from rubbing, we must measure the extent to which the samples are worn when, under a given load, they are subjected to the rubbing of a normal sand spread evenly about on a circular horizontal cast-iron plate, which is moved at a given speed.

The dimensions of the samples will be 2·36 by 1·57 inches base, and a height varying from 3·93 to 4·72 inches; they will be put two and two on all sides of the axis and on the same diameter as the mill, in such a way that the centre of them will be on a circumference of 10·275 ins. radius, the small dimension being placed perpendicularly to the radius.

The total load on the plane of rubbing will be from 250 grammes per square centimetre.

The usual sand used will be obtained by pounding and then sifting quarzeous, moderately hard, Fontainebleau stoneware, passing through a sieve No. 50 (324 meshes) and kept entirely back on a sieve No. 200 (4,900 meshes).

The quantity of sand to be spread on the mill will be one litre per test piece

### 4. *Resistance to Breaking by a Blow.*

The experiments being now in process, rules cannot yet be fixed for this test.

These experiments will be continued.

### 5. *Resistance to Breaking by Internal Pressure.*

*Special Tests for Pipes.*—The tests for resisting breaking by internal pressure will be made either by the help of a forcing pump, or by means of a hydraulic accumulator.

The unit of pressure adopted is the kilogramme per square centimetre, and the figures, when not otherwise mentioned, are in relation to the pressure used.

The pipes to be tested ought to be exactly filled with water. It is important that the pressure should be gradually and not suddenly produced. The manometre ought to show, without any chance of mistake, the pressure exerted in the pipe itself.

The test could be made either on a separate pipe, or on several pipes put together.

The joints that close the extremities of the pipes should be arranged in such a way that they will not fly, and be made in such a manner that the tightening of them will not lead to a premature bursting of the pieces subjected to the test.

The Committee expresses the opinion that the tests now in progress for finding a suitable method of closing the ends of the pipes should be continued.

## *Chemical Tests.*

### 1. *Testing for Lime and Magnesia.*

With the object of determining whether there is in the terra cottas any lime or caustic magnesia, five samples will be immersed for three hours in boiling water, and notice will be taken whether, under these circumstances, any exfoliations are produced.

and per 1,000 turns of the mill. The apparatus will be turned at the rate of 1,000 turns per half hour, and the sample will be subjected to 4,000 turns of the mill. The diminution in height of the sample will be measured and the loss in weight which it has sustained will be determined. The same particulars will be noted in the course of the test after 1,000, 2,000 and 3,000 turns.

The sample may be turned over from end to end after 2,000 turns of the mill, so as to compare the results obtained on the lower and upper faces.

### 2. *Determination of the Soluble Salts.*

In order to determine the proportion of soluble salts that may be contained in a terra cotta, five samples should be taken, which by preference are chosen in the middle of the terra cottas, and are powdered so as to make them pass entirely through a sieve of 900 meshes. Three hundred grains of the powder thus obtained is taken and boiled for an hour in ten times its volume of distilled water, replacing the water that has evaporated. After it has been filtered it must be evaporated to dryness, and the residue thus obtained must be weighed.

# CHAPTER X.

## FIRECLAY GOODS.

SUMMARY.—Classification.

SEC. 1. *Argillaceous Fireclay Goods:* Forms, Dimensions and Properties—Resistance of Fireclay to the high Temperatures—Composition and Preparation of the Body—Moulding—Drying—Burning—General Arrangements of the Manufactories for Fireclay Goods.

SEC. 2. *Aluminous Fireclay Goods.*

SEC. 3. *Carboniferous Fireclay Goods.*

SEC. 4. *Silicious Fireclay Goods.*

SEC. 5. *Basic Fireclay Goods.*

SEC. 6. *Fireclay Mortar* (Pug).

SEC. 7. *Tests for Fireclay Goods.*

**232. Classification.** — Fireclay goods are distinguished from all others by their resistance to the action of heat. Heated to the temperature for burning hard porcelain, yet they do not become vitrified. They are naturally always dull and of a more or less yellowish-white, or else slightly greyish colour, except one variety, of which we shall speak later on, which is black.

We have seen, at the beginning of this work, that among the wares are classed certain fireclay goods in which the clay is replaced by other agglutinants, because these goods are manufactured by means of the processes used in pottery. The following classification, therefore, includes not only fireclay ware, but also the productions to which we have just alluded. It is for this reason that this chapter, which from a ceramic point of view ought to be entitled *Fireclay terra cottas*, has been headed *Fireclay Goods.*

The most natural classification of these productions rests on their chemical composition. It is, in fact, that which should guide us in the choice of the different kinds of fireclay productions

for their use in kilns. Besides, it allows of our judging beforehand of their resistance to heat.

Chemically, they may be divided, as M. Jordan does the fireclay productions, as follows:—

*Acid productions*, that is to say, those formed of pure silicate of alumina, of a mixture of silicate of alumina and silica, or of silica nearly pure; their acid properties being as much more developed as the proportion of silica is larger.

*Basic productions*, containing a large proportion of lime or magnesia, or of a mixture of these bases.

*Neutral productions*, formed of silicates of alumina that are more aluminous than pure clay, noticing that the alumina plays the part either of a base with acids, or the part of an acid with certain bases, as lime, for example.

*Reducing or carburetting productions*, containing a larger or smaller amount of carbon.

*Oxidising or decarburetting productions*, formed with the ores of peroxide of iron.

These last goods up to the present have only been used for the fittings of some kilns, and not as fireclay productions properly so called, manufactured in special manufactories. We need not therefore discuss them in this work.

By starting with pure clay we see that this makes slightly acid goods, because, when sufficiently strong bases are present, pure clay, which is a bisilicate, may be changed into a monosilicate, thus giving up one equivalent of silica. It is understood, of course, that these reactions only take place at high temperatures.

By adding more and more silica to the clay the acid properties are increased, the same as by adding alumina they are diminished, until they are completely neutralised, when the composition of the ware corresponds to that of a monosilicate of alumina. On the other hand, by continually adding a sufficiently large proportion of lime or magnesia, ware of a basic reaction is obtained, and, lastly, by adding carbon to it, reducing or carburetting ware can be made.

Such are the different kinds of fireclay terra cottas that can be obtained by taking clay as a basis. But one may take

also either silica, lime or magnesia as a starting-point, and manufacture goods containing as high a proportion as possible of these substances, but adding to them only the quantity of agglomerant strictly necessary to allow of their being manufactured. In this case the substance to bind them together can either be clay or any other material answering the same purpose. The fireclay goods thus obtained are not pottery.

The preceding remarks allow the different kinds of fireclay goods to be classed very exactly. It is, however, very necessary to make one important remark on this subject. Except in rare instances, all the fireclays contain silica in excess. A distinction between the fireclay goods of pure clay and those composed of a mixture of pure clay and silica would not answer the conditions for use; having regard to this remark, the following classification has been adopted:—

1. *Argillaceous fireclay goods*, more or less acid, having natural fireclay as a base.

2. *Aluminous fireclay goods*, slightly acid or neutral, formed of a mixture of clay and alumina, or rather of compounds relatively rich in alumina.

3. *Carboniferous fireclay goods*, reducing and carburetting, in which there is a decidedly large proportion of carbon.

4. *Silicious fireclay goods*, strongly acid, formed almost exclusively of silica.

5. *Basic fireclay goods*, containing a preponderating proportion of lime, magnesia, or of a mixture of these two bases.

Sometimes chromate of iron has also been employed as a refractory material, which resists acids as well as bases, and bears a very high temperature; but bricks of this kind are a metallurgical production and do not belong to pottery.

### I. *Argillaceous Fireclay Goods.*

**233. Shapes, Dimensions and Properties.** The manufacture of argillaceous fireclay goods in special factories only dates from the beginning of the nineteenth century. Before that it was mixed up with that of ordinary bricks. Experience alone could distinguish the bricks which best resisted the action

of heat, and which were used in preference for building kilns. It is only by precise chemical analysis of the clays that it has been possible to distinguish scientifically the fireclays from the other clays, and to decide the composition that they must have to be able to resist high temperatures and the attacks of the materials with which they come in contact in the kilns. A great advance was also made in this direction when the clays were opened by means of a grog of fireclay terra cottas (Art. 42), instead of using sand, as is the case for ordinary bricks. This process was known for a long time, but it is only since the beginning of the nineteenth century that it has been used methodically.

Fig. 273 shows some of the most usual applications of argillaceous fireclay goods. Naturally, they are only given as a sort of example, because the shapes may be infinitely varied. Plain bricks are usually of the shape and dimensions of building bricks (I.): in France, 8·66 × 4·33 × 2·36 inches; in England, 9·44 × 4·72 × 3·15 inches; and in Germany, 9·84 × 4·92 × 2·56 inches. In the usual way, knife-shaped bricks (II.) and wedge-shaped bricks (III.) are made for building domes. There are, besides, a large number of special patterns, and, as will be seen further on, the manufacturers can easily make when wanted even the most different and most complicated patterns (V.). When the pieces are much above the dimensions of ordinary bricks they are called blocks. These latter are better for building kilns, so as to lessen the number of joints, which are always a weak place in masonry. Yet, if possible, the dimensions of a length and width of 24 inches by a thickness of 15¾ inches should not be exceeded. Above that the blocks are rather unwieldy, and there is a risk of their not being burnt enough in the middle.

Slabs (VI.) are also manufactured of a thickness of 1·57 to 3·94 inches, by a length that may exceed 39 inches, and a width of 20 to 24 inches.

In some cases hollow goods are used, such as tubular bricks for receivers (Fig. 180), gas burners (VII.), channels (VIII.), etc., etc.

Lastly, we may mention some special kinds that are much

used, such as muffle kilns, ordinary crucibles (IX.), the height of which varies from 2 to 24 inches; glass crucibles, ordinary

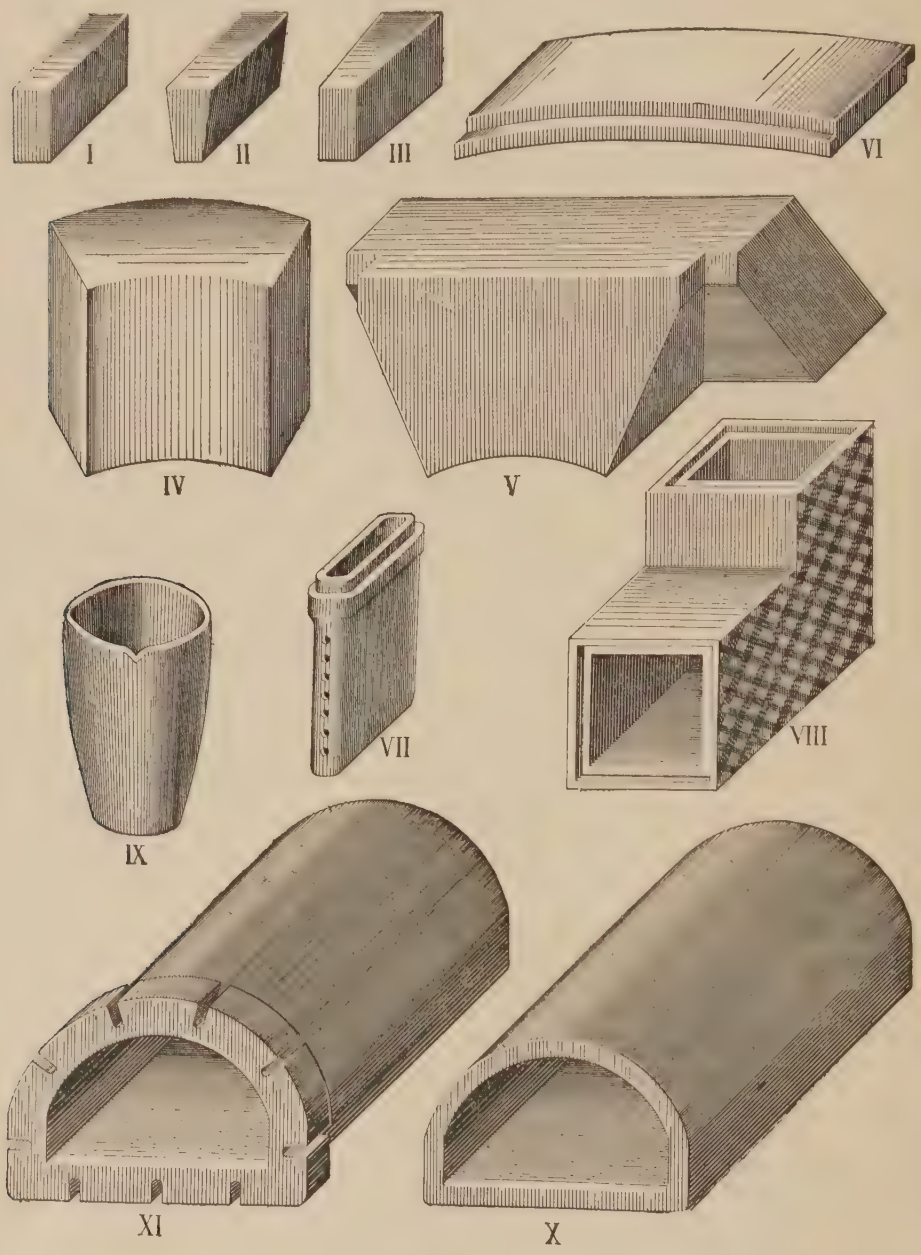


Fig. 273.—Fireclay Goods.

retorts (X.), being as much as $27\frac{1}{2}$ inches wide by $19\frac{1}{2}$ inches high and more than 39 inches long; gas retorts (XI.), being as

much as 29½ inches wide, 17¾ inches high, and 6 ft. long; laboratory furnaces, etc., etc.

All pieces, whether of such various shapes or for various purposes, ought, as far as possible, to fulfil the following conditions:—

1. They must resist, without warping, the highest temperature to which they can be subjected. This resistance to heat depends mainly on their chemical composition and partly on their physical texture, as we shall see further on.

2. They should bear without cracking or breaking somewhat rapid variations of temperature. On this subject it must be remarked that it is not the variations of temperature themselves that are to be feared, but the differences of temperature between the parts of the same ware, differences which are the more difficult to prevent in proportion as the heating or cooling is more rapid. Thus, a thick crucible might break under some conditions of heating that a thinner crucible would have resisted. The lower the texture of the ware and the less it is burnt, the more quickly the temperature of the mass is equalised, and the less liable it will be to crack or break. While in dense pastes that are more or less vitrified the conductibility is weaker, it is more difficult to keep the temperature equal, and the result is that it dilates differently, and this causes unequal tensions that the mass cannot resist.

3. Lastly, fireclay goods ought to resist the attack of the different materials with which they come in contact in the kiln. Those which principally exert a harmful influence are the ashes of the fuel, and either the materials themselves that are heated or the gas which may escape from them. We must first remark upon this subject that argillaceous fireclay goods, being more or less acid, are easily attacked by all substances that are susceptible of forming silicates when united with silica, that is to say, those which contain alkaline bases, alkaline earths, or certain metallic oxides. With a low temperature an opposite reaction may be produced; the acid effects are then capable of displacing the silica from its combination with the alumina and the other bases contained in the body. The attacks on fireclay goods are the more vigorous the more porous these wares are,

and weaker the more dense they are, or when burnt at a higher temperature.

We see that the two preceding conditions are contradictory, that it is impossible to make ware that can at the same time bear a rapid heating and the attack of alkaline ashes, or the corrosive action of melted glass, for example. It is best, in each particular case, to establish a medium, which only experience can determine as a rule.

Finally, we will observe that, from the point of view of a good construction of the kilns, if the fireclay goods have to be submitted to a higher temperature than that to which they were submitted during the burning, they will usually shrink to a certain extent, and this may cause cracks or dislocation of the masonry. If the bodies contain a considerable proportion of quartz the opposite may occur, in consequence of the expansion that takes place in quartz when, under the influence of a great and prolonged heating, it passes from the density 2·7 – 2·6 to the density of 2·3 – 2·2.

234. Resistance of Fireclays to High Temperatures.—In the chapter on baking was discussed the part that the different materials of the body play as to fusibility, as well as the modifications caused by burning on the different properties of the body (Art. 145). As the chemical composition of fireclays plays so large a part in their resistance to high temperatures, a more important part than in any other kind of ware whatever, it is necessary now to enter into supplementary details on this subject.

We have seen that the natural fireclays are composed of pure clay, of silica and fluxes, these latter being always in a small proportion, but the amount of silica may be raised as high as 50 per cent. (Art. 30). Under this term of natural fireclays must be included not only clays properly so called, but also kaolins, so long as they are neither too alkaline nor too ferruginous, so that they may be used in the manufacture of fireclay goods. In order to simplify the examination of the refractory properties of clays, we will first discuss the influence that is exerted on pure clay by the addition of various proportions of silica and alumina; then we will examine the action of the fluxes.

The bisilicate of alumina or pure clay melts at the temperature

corresponding to Seger's test No. 36 (Art. 180). This temperature has not been precisely determined: it seems to be nearly that for fusing platinum (1,775° C). Whatever it is, we notice that the fusion is easier the more an increasing proportion of silica is added to the pure clay, until the mixture contains one equivalent of alumina to 17 of silica (90·83 per cent. of silica; 9·17 per cent. of alumina). From that point, if the amount of silica is further increased, the body becomes more refractory again, until when it contains only pure silica (rock crystal) it attains a temperature corresponding to Test 35, that is to say, for fusing pure clay containing trace of alkalies. If, on the other hand, alumina is added to pure clay, the mixture becomes more and more re-

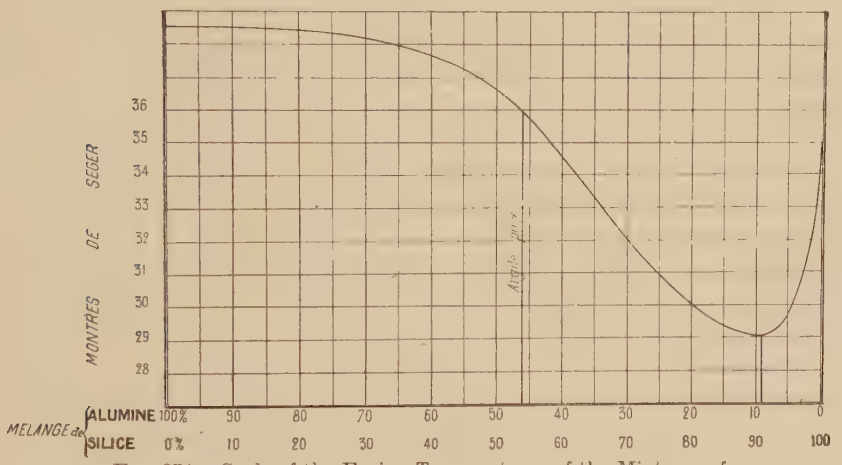


FIG. 274.—Scale of the Fusing Temperatures of the Mixtures of Silica and Alumina.

fractory. Lastly, pure alumina, such as is found in cryolite, resists a temperature above any of the preceding ones, and does not show any trace of vitrification at the temperature for fusing platinum.

Fig. 274 represents in a graphic form the foregoing remarks. The temperatures are calculated according to Seger's tests, and the curve of the fusing temperatures shown reproduces what that clever potter has given, but by replacing the division into equivalents by the centesimal proportion of silica and alumina.

As to what concerns fluxes, we have said that, according to Richter, it is admitted that their action, from the point of view

of fusibility, is in proportion to their equivalents, that is to say, that 20 parts of magnesia would act the same as 28 of lime, 31 of soda, 36 of protoxide of iron, and 47 of potash. This rule would seem also to apply to the peroxide of iron, which appears to be as infusible as alumina, and the equivalent of which is 80. However, we should not consider, in the absence of decisive experiments, the foregoing equivalents as a law, but only as a general reckoning. Concerning the oxides of iron, we must also remark that at high temperatures the peroxide is always more or less changed into the protoxide.

It is well known, as we have already observed, that these relative fusibilities of the different fluxes, can only be precise at high temperatures, at the moment when, the whole mass of the body being softened, a compound is formed which is chemically determined by the global analysis. It is no longer noticeable in the same way at a lower temperature, because then the fluxes may be mixed up with those combinations which are still fireproof at that temperature. It very frequently happens with the alkaline fluxes, which are often found in the bodies in the form of feldspar, and which can only act when that rock begins to be vitrified. It is also the same with lime when found as the sulphate.

M. Bischof, in some very extensive experiments on fireproof goods, but before Seger's work, had tried to define by a number the degree of fusibility of fireproof clays. He based it solely on the chemical composition, taking as a basis the proportion of fluxes expressed according to their equivalents and comparing with that the proportion of silica and alumina. In this way he arrived at representing the composition of the clays by a symbol in the form

$$a.Al^2O^3 + b.SiO^2 + RO.$$

RO taken as the unit representing the fluxes, $a$ and $b$ indicating the amount of alumina and silica in proportion to those fluxes. He admitted that the coefficient of fusibility was given by the quotient, of the proportion of alumina by the relation of silica and alumina, that is to say, that it is equal to $a$ divided by $\frac{b}{a}$ or to $\frac{a^2}{b}$.

In support of his argument M. Bischof mentioned seven natural typical fireproof clays, having the coefficients varying from 13·95 to 1·64, the highest number corresponding to the most refractory.

M. Bischof's theory seems to correspond fairly well with the direct pyrometric results; but the use of it is very doubtful, because it rests on a chemical analysis, which is more difficult to obtain with the precision which is indispensable than to make a direct test by fusing it, taking as a guide Seger's tests. We only mentioned this theory because it has still fairly numerous partisans in Germany.

The following table reproduces, as a comparison, the composition of the seven typical clays of M. Bischof:—

| | Altwasser Clay. | Zettlitz Kaolin. | Andennes Clay. | Mulheim Clay. | Grunstadt Clay. | Cassel Clay. | Niderpleis Clay. |
|---|---|---|---|---|---|---|---|
| Silica | 43·84 | 45·68 | 49·64 | 47·74 | 47·33 | 57·99 | 58·32 |
| Alumina | 36·30 | 38·54 | 34·78 | 36·00 | 35·05 | 27·97 | 28·05 |
| Oxide of iron | 0·46 | 0·90 | 1·80 | 2·57 | 2·30 | 2·01 | 1·89 |
| Lime | 0·19 | 0·08 | 0·68 | 0·40 | 0·16 | 0·97 | 0·72 |
| Magnesia | 0·19 | 0·38 | 0·41 | 0·33 | 1·11 | 0·54 | 0·75 |
| Potash | 0·42 | 0·66 | 0·41 | 1·05 | 3·18 | 0·53 | 1·39 |
| Loss in the fire and various | 17·78 | 13·00 | 12·00 | 11·81 | 10·51 | 9·43 | 8·66 |
| | 99·18 | 99·24 | 99·72 | 99·90 | 99·64 | 99·44 | 99·78 |

The preceding figures can be put in another way, by separating the clay from the silica and reducing all the fluxes to protoxide of iron, in relation to their equivalents. The protoxide of iron has been chosen as the point of comparison, because it is usually the flux found in the largest quantity.

The following are the numbers thus obtained:—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pure clay | 92·34 | 91·51 | 84·49 | 87·28 | 83·34 | 67·95 | 64·24 |
| Silica | 6·00 | 5·96 | 11·29 | 7·66 | 8·98 | 26·93 | 30·18 |
| Fluxes reduced to protoxide of iron | 1·66 | 2·53 | 4·22 | 5·06 | 7·68 | 5·12 | 5·58 |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |
| Temperature for fusing calculated according to Seger's tests | No. 36 | No. 35 | No. 33 | No. 32 | No. 30 | No. 28 | No. 26 |

The first two clays are almost pure clays, the three following ones are plastic fireproof clays, and the last two are silicious fireproof clays.

235. Composition and Preparation of the Body. The fireproof bodies are composed solely of clays or kaolins, with the addition, when necessary, of some opening material—fireclay grog or quartzeous silica. For very plastic clays the proportion of opening material may be two parts by weight to one part of clay, while for very silicious clays it may happen that it is not possible to open them.

The use of silica as an opening agent has the disadvantages of modifying the chemical composition, of reducing the temperature at which the terra cotta can resist, of not allowing the grains to be as coarse as is desirable, and of making it liable to swell, and even crumble, in consequence of the expansion of the quartz. Also, for all fireclay goods of a good quality only grog should be used as an anti-plastic material. As the fireclays that are decidedly silicious are only pure clays thinned with sand, they naturally present all the disadvantages already pointed out, and they can never make fireclay goods of the first quality. We must, however, while on this subject, remark that in working the cases are very frequent in which medium or even inferior goods will be used, as they have the advantage of being cheaper, a consideration which at the present time is thought a great deal of.

The largest part of the grog used in the manufacture of fireproof goods is furnished by the rubbish of fireclay wares, bricks, crucibles, retorts, saggers, etc. This rubbish, which is thus of some value, is bought by all the manufacturers for grinding up in one of the apparatus that have been already described, and then sifted so as to obtain grains of various coarseness. If sufficient of this grog cannot be obtained, then natural clay is burnt in balls in the kilns that are used for burning the ware. It is very seldom that special kilns are used for this purpose.

Fireclay is usually dug out a long time beforehand, then dried in the open air or in kilns on purpose, and finally powdered.

The mixing of this clay and the grog is done in bulk by putting the two materials into a working-up machine, where the desired proportion of water is added to them. In well

arranged factories the clay powder and the grogs of different coarseness are stored in hoppers placed in the upper part of the buildings, from which they naturally run down into the working-up machine.

This latter may be either vertical or horizontal. The latter is the one usually preferred, because the body is closer and contains fewer air bubbles. A very good method consists in first using the working-up machine shown in Fig. 35 (page 159), and afterwards passing the body through a second machine for working it up, which is a horizontal one, and which makes the body into large blocks. These are afterwards kept for some time in a damp place, before being used for moulding.

We must now say a few words about some special compositions of fireclay ware. In a general way, it is best to use as infusible a clay as possible; however, in some cases it is advisable to use clays which, at the temperature at which they are burnt, show sign of beginning to soften. In that case the body becomes closer and can better resist the attacks of the materials with which they come in contact in the kilns. This is the case, for example, with glass crucibles or those for the kilns in which decidedly basic or acid vapours are given off. It is well known that then the burning of the ware must be carried on at a temperature above that which it will have to bear when in use.

When it is required, on the other hand, to manufacture terra cottas that will resist rapid changes of temperature, as much grog as possible must be incorporated with the clay, the former being of a fairly coarse grain. The dimensions of these grains depend, besides, on that of the object to be made. For thick blocks they may be as much as ·2755 in.; they can be reduced to ·0787 in. for thin ware. By employing coarse and fine grains at the same time the latter come between the former and allow a larger proportion of cement to be mixed with the clay.

**236. Moulding.**—The making of argillaceous fireclay goods is either by moulding by hand or by drawing.

In the first case the body employed must be of a decidedly firmer consistency than that used for moulding ordinary bricks,

because it is essential to obtain more compact goods. This consistency necessitates the body being pushed or beaten inside the mould, instead of being made in the manner described in the preceding chapter. The result is also that the moulds must be more solidly made. They are of wood, the joining being done with wooden corners or bolts. For large pieces it is sometimes necessary to strengthen them with iron bands.

This moulding by hand, to be very successful, needs not great professional skill, but care and regular work. The following are some short instructions on the subject of special methods for different forms of ware.

Ordinary bricks are made in moulds similar to those used for bricks for building, but the output is much less, because of the firmness of the body. Larger pieces and blocks are pushed into the moulds in horizontal layers. When the shapes are complicated, or when there are empty parts, then a sort of sketch is moulded, that is afterwards carved very easily. Some round pieces can be turned, but this operation is not, usually, very easy, because of the granulated texture of the body.

For hollow pieces of a large size, such as a crucible for glass making, or a gas retort, they begin by making the bottom on a plank of wood, either by putting pellets of clay side by side, or by sticking together slabs cut off from the blocks of body prepared in the mixing machine. In any case the bottom is roughed out first with a thickness decidedly greater than is needed, then it is reduced by pushing it, in such a way as to make the body spread out towards the edges. Round this bottom is then placed the mould that is to be used for the walls, and on this is put the body, beaten out and suitably joined together. Fig. 275 shows the moulding by this method of a crucible for making glass, the mould being in two pieces, joined together by bolts or hooks, so that it can be emptied. In Fig. 276 is shown the making of a gas retort; in that case the mould is in several pieces, joined by pins, which are put on one another in proportion as the moulding advances. The inside shape is obtained by smoothing the surface with the hand, and passing a templet over it, or by measuring the thickness of the body by means of a pair of compasses.

Plain ordinary bricks can also be made by the pipe machines already described. By inclining the wires of the cutting board, bricks with sloping sides or wedge-shaped ones can be made.

For hollow goods of a rectangular section, on account of the small number made, piston propellers worked by hand are generally used. On the contrary, crucibles or retorts, with a cylindrical or prismatic section, are made by expression by means of vertical piston propellers. The machines used for this purpose are arranged in the manner which will be described and shown further on (Fig. 311, page 685), and which is used in the manufacture of stoneware pipes of large diameter. The bottoms are always added and joined to them by hand.

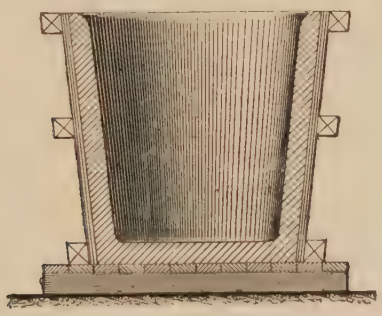

Fig. 275.—The Moulding by Hand of a Crucible for Glass Making.

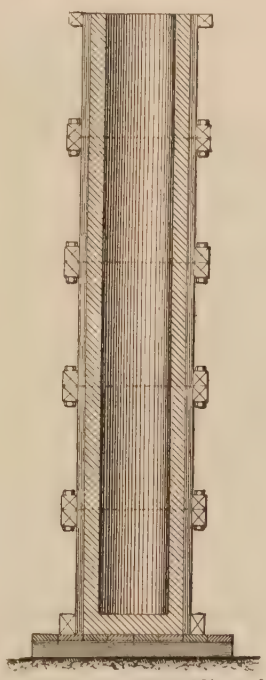

Fig. 276.—The Moulding of a Gas Retort by Hand.

Some goods, as, for example, saggers, are made by moulding slabs of the body, first by hand. This moulding is done on a table dusted over with grog, on which are fixed four rules, the thickness of them being equal to that of the slab. The body should be firm enough for this roughing out to be done by striking it with a wooden bat. The slab thus moulded is smoothed, then rolled round a wooden mould, which has the inside shape of the sagger. When there is a bottom to it, the mould is placed on another circular cake of body, and the whole is joined together by hand, also making use of the bat. To take it out of the mould it is sufficient to strike the body,

which is slightly lengthened, becoming detached from the mould, which is then drawn out vertically.

This operation can be replaced by a kind of machine

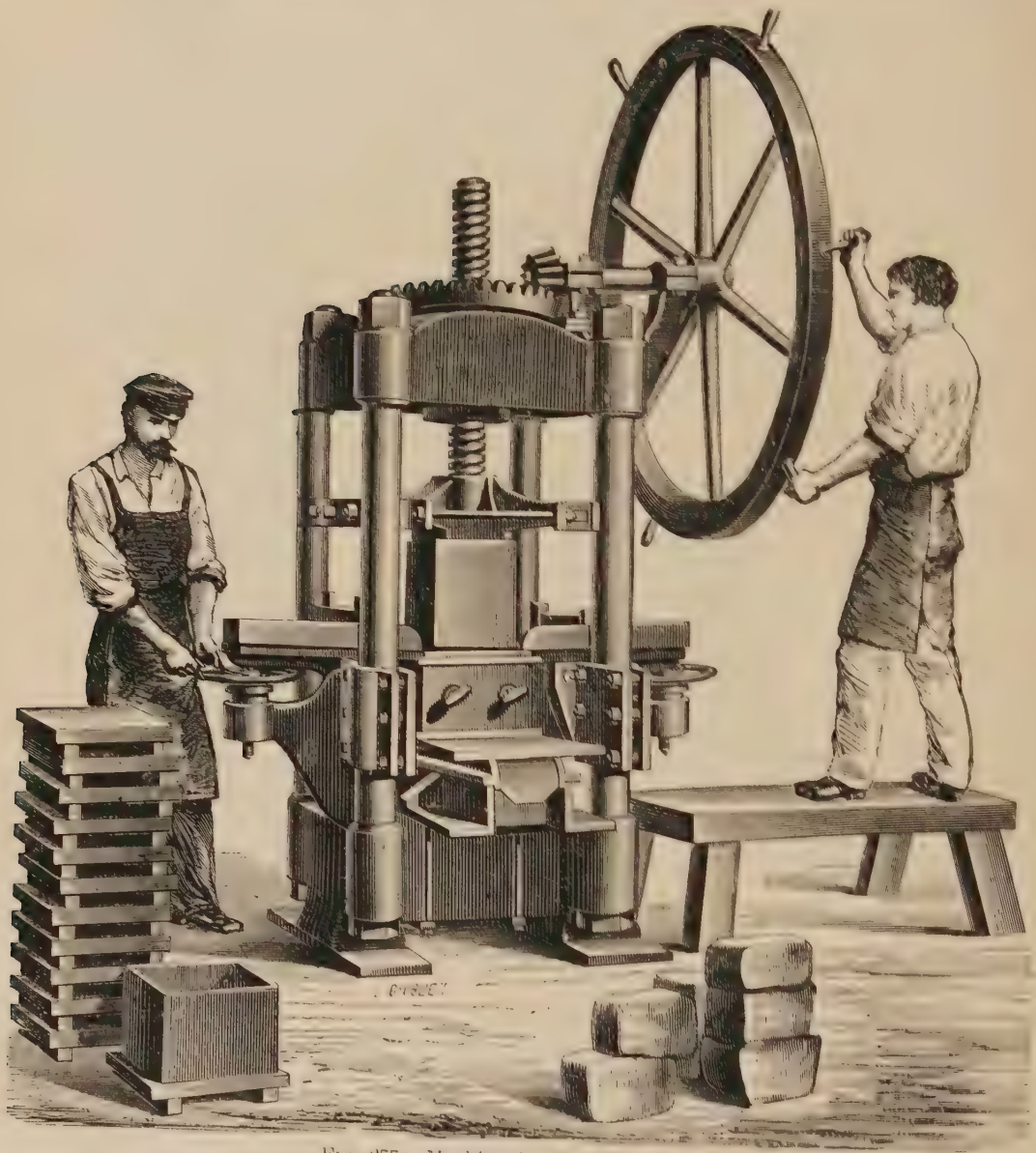

Fig. 277.—Machine for Moulding Saggers.

moulding. In that case the slabs of body are placed in the interior of a mould, the form of which corresponds then to the outside of the production; then a piston is pushed in,

which presses the body together and makes it join. Fig. 277 shows a machine of this kind made by M. Wenger. The production is from twelve to fifteen saggers an hour when the machine is worked by hand, and twenty-five to thirty when worked by an engine.

Lastly, in some cases crucibles can be made on a turning lathe. There will be given, when on the subject of the manufacture of carboniferous fireclay goods (Art. 241), an example of a machine of this description.

The comparison between the goods moulded by hand and those obtained by mechanical drawing has often given rise to disputes. If the former are more porous, and if their success depends on the care taken by the workmen, yet the latter have the defects which have been mentioned before as belonging to all drawn goods. We may consider that at least both processes are good, but on account of the cost of putting up the machines for moulding, they only answer when large quantities of similar pieces are made.

**237. Drying.**—The drying of fireclay goods, when thin or of a small size, does not present any difficulty; it is done by the same methods as those employed for plain building bricks. It is not so with thick and heavy goods that are difficult to handle, and which, unless made in a warm, dry climate, can only be completely dried in artificial drying sheds.

When the moulding is done by hand the goods are usually left to dry in the mould for about twenty-four hours, and then taken out and carried to the drying shed. This is a room heated either by pipes running under the floor or else by means of a hot air stove. In the former case the waste heat from the kilns or from the steam boiler can be used. The drying must be done as much the more slowly as the pieces are thicker; sometimes it takes several weeks. In theory it is better to have several drying sheds, so as to graduate the temperature according to the advance in the stages of drying. From time to time, if the shape will permit, the pieces are turned over so as to render the drying uniform.

In some potteries the drying is done in the moulding shop, in which case it is best for this to be heated, unless favoured with a special climate.

**238. Burning.**—The burning of argillaceous fireproof goods is usually done in round kilns with descending flames, like those described on page 359 (Fig. 161). The volume of these kilns varies from 1,400 to 5,150 cubic feet, the diameter being equal to or slightly larger than the height.

According to the amount of damp in the ware, and to the dimensions of it, the length of the slow firing may vary from twelve hours to two days. The hard firing needs from two to three days. The consumption of fuel is extremely variable, on account of the great differences there are in different factories, as much from the nature of the body as from the temperature at which they are burnt. In some works 290 lb. of fuel to a ton of ware is sufficient (coal of a rather good quality); in others it is necessary to use 550 lb. and even 670 lb. On this subject we must remark that for kilns of the same system, equally well managed, the higher the temperature of burning is raised, and consequently the greater the consumption of fuel, the better the quality of the goods.

The following, but only by way of example, is the thermic yield of one of these kilns:—

| | | | |
|---|---|---|---|
| Heat produced by combustion . | 100 | Heat theoretically necessary . | 35 |
| | | Heat lost by heating the walls . | 15 |
| | | Heat lost by radiation . . . | 15 |
| | | Heat lost through the chimney . | 30 |
| | | Heat lost by incomplete combustion | 5 |
| | 100 | | 100 |

For burning bricks and blocks kilns with continuous firing can also be used, heated by coal, similar to those used for burning ordinary bricks. In that case there is a certain proportion of goods spoilt by the contact of the fuel; but, as the consumption of fuel is reduced by 176 to 264 lb. per ton of ware, from a thermic point of view it would be wiser to use this class of kiln. The use of gas fuel in kilns with a continuous firing with one burning space needs slightly more fuel, but all the goods are whole and generally well burnt. This solution, except for the general remarks as to kilns with continuous firing, which will be made later on, is certainly the best for burning fireclay bricks and blocks.

For burning retorts, crucibles, etc., for a very large quantity

continuous kilns can also be used, but those with several spaces. We must remark that, in this kind of kiln, the accumulation of heat is less than in kilns with one chamber, and that the heat lost by heating the walls is much greater. There is no reason then for preferring them when, as for retorts, the flames ought to be descending, or when the production of crucibles, for example, requires a very regular raising of the temperature.

If, in a general way, continuous kilns are more economical for burning fireclay goods, it is necessary to state that they are only of commercial value in the case of the manufacture of a large amount. In the fireclay goods industry the orders are somewhat irregular; it is difficult to manufacture for stock, because of the various shapes and qualities of the goods, so that, commercially speaking, it is sometimes better to choose, instead of continuous kilns, the intermittent kilns for a production which is decidedly variable, these adapting themselves better to the needs of the business.

**239. General Arrangements of the Manufactories for Fireclay Goods.**—The manufacture of fireclay goods is sometimes carried on in brickfields or tile works. Then, usually, the fireclays taken out in the neighbourhood are used, and the implements employed in making ordinary bricks are made use of for the manufacture of firebricks of the most common types. The goods thus obtained are generally of a medium or inferior quality, which, on account of their relatively low price, are used for numerous industrial purposes which do not need a better quality.

The important metal works, glass works, some gas works, faience works, porcelain works, and some chemical works also manufacture the fireclay goods which they need. They prepare the grog with their waste and buy the fireclay. In those works therefore there is no need to economise on the price of the purchase, but they must have fireclay goods that are of the right quality, that practice has shown to be the best for that purpose. These special arrangements have nearly always bad implements and are relegated to some corner of the works.

Lastly, there is a certain number of special factories for fireclay goods. Most of them are placed near the clay beds, when these are not too far from the centres of consumption.

The price of the fuel, which, we have seen, is an important factor in the cost price, also exerts a certain influence on the placing of these factories. In some rarer cases they prefer to place the works in the middle of a centre of consumption and transport the raw materials. However that may be, the general arrangement of a factory for fireclay goods is very simple. The drying sheds being generally on the ground level, all the factory is composed of sheds, in which are arranged the shops for preparing the body, for moulding, the drying sheds and the kilns. It is also necessary to keep the goods, when made, sheltered from the rain, if you do not want to see them become a disagreeable green colour, due to vegetation.

The cost price of argillaceous fireclay goods varies, according to the quality, the shape of the goods, and the more or less favourable situation of the works, from 17 to 80 francs a ton. The unit of sale is usually the 100 or the 1,000 kilogrammes. The factories of moderate importance manufacture from 3,000 to 5,000 tons a year, the most important ones may reach as much as 40,000 tons.

### 2. *Aluminous Fireclay Goods.*

**240.** The aluminous fireclay goods are used when it is necessary to have neutral goods, only slightly attackable by alkalies, and resisting high temperatures. The silicious fireclays which contain at most 30 per cent. of alumina in a natural state, or about 33 per cent. when burnt, cannot be used for the manufacture of truly aluminous goods. The plastic fireclays, with a proportion of 30 per cent. to 35 per cent. of alumina, produce goods having from 34 per cent. to 40 per cent. of alumina. Lastly, some very pure clays contain, when burnt, as much as 43 per cent. of alumina.

One generally reckons as aluminous fireclay goods all those that contain more than 33 per cent. of alumina. Yet this amount is insufficient to combine entirely all the silicate in the form of bisilicate, and theoretically only those goods can be properly called aluminous which have an amount of alumina greater than that of pure clay.

Therefore it is necessary to introduce into the bodies, even

the most plastic ones, a supplementary quantity of alumina. Unfortunately, the very aluminous minerals are rare and often of an inaccessible price. Up to the present time scarcely any, except some kinds of halloysites or lenzenites and the bauxites, have been able to be used.

Among the last, the varieties containing the least oxide of iron must be chosen. The composition of certain bauxites which are suitable for manufacturing fireclay goods has been given (Art. 47). Although these bauxites are hydrated silicates of alumina, they are deprived of all plasticity, at least in the state in which they are found in nature. They cannot then be introduced into the bodies except as thinning materials, that is to say, their proportion must not be more than 66 per cent. If a fairly pure plastic clay is taken, containing, when burnt, 33 per cent. of alumina, 60 per cent. of silica and 4 per cent. of fluxes, and mixed with it is a bauxite containing 76 per cent. of alumina, 18 per cent. of silica and 6 per cent. of fluxes, a ware could be made having a maximum of 61 per cent. or 62 per cent. of alumina with 33 per cent. of silica, that is to say, which corresponds to the composition of a monosilicate of alumina. We have seen before that it is this combination that is needed in order to obtain really neutral goods.

Bauxite is found in the shape of rocks, sometimes rather hard, or as an earth, which must be well calcined and reduced to powder before being mixed with the clay. It must not be mistaken for the fireclay grog, for the latter, having the same composition as the clay, may remain in the shape of coarse grains without altering the composition of the body. The bauxite, on the contrary, must be very closely mixed with the clay, so that the mass may have a homogeneous composition. The result is that the goods thus obtained are close, and resist well the attack of the ashes or vapours of the kiln, but bear rapid changes of temperature badly.

The manufacture of aluminous goods is the same as that of argillaceous goods and is carried on in the same factories.

It has also been attempted to bind together bauxite powder with different agglutinant materials, and for this purpose tar and silicate of soda especially have been used. This manu-

facture then becomes similar to that of silicious fireproof ware, which will be discussed further on.

### 3. *Carboniferous Fireclay Goods.*

241. The carboniferous fireproof goods fulfil all the conditions required in fireproof materials; resistance to the highest temperatures, to the rapid variations in the heat, to ashes and the other materials with which they may come in contact. They have, on the other hand, the disadvantage of being burnt up rather rapidly and of being very dear. They are seldom used for bricks or blocks, but are very much used for the manufacture of crucibles, called plumbago crucibles, which are made use of in several metallurgic operations, particularly on account of their reducing or carburetting qualities.

The carbon used is blackload, which is found in nature, or even the deposit of carbon that is formed in gas retorts.

Graphite, or plumbago, is a mineral of a metallic grey black, crystalline, greasy to the touch, leaving marks on the fingers. Its density is 2·1. It is found in France at Chardonet (Hautes-Alpes); in Germany at Passau; in England at Borrowdale and Keswick (Cumberland); in Austria-Hungary at Mugram (Austria), and in several localities of Moravia and Styria; in the United States at Sturbridge (Massachusetts), at Ficouderora (New Jersey), at Fishkill (New York), and in some localities in California; somewhat important beds are found in the island of Ceylon, but the most important mines are those of Inisei in the Batougal and Oural mountains, and on the banks of the river Anotte in Siberia. It is only met with in the primitive strata in the middle of gneiss, granite, mica-schists or calcareous saccharoids.

The proportion of carbon varies from 75 per cent. to 97 per cent., the remainder being formed of a quartzeous, or sometimes quartzeous and aluminous gangue.

The carbon from gas retorts is generally purer, but the price of it has risen considerably since a use for it has been found in large quantities in the manufacture of carbons used in the electrical industry.

Carbon, in whatever form it may be employed, is first

powdered, and then mixed with the clay which has also been reduced to a powder. The quantity of carbon mixed in varies from 25 per cent. to 50 per cent., according to the carbureting action that it is required to give to the crucible. A part of the clay may be in the form of grog reduced to fairly fine grains. Sometimes magnesia is also added to it in one of

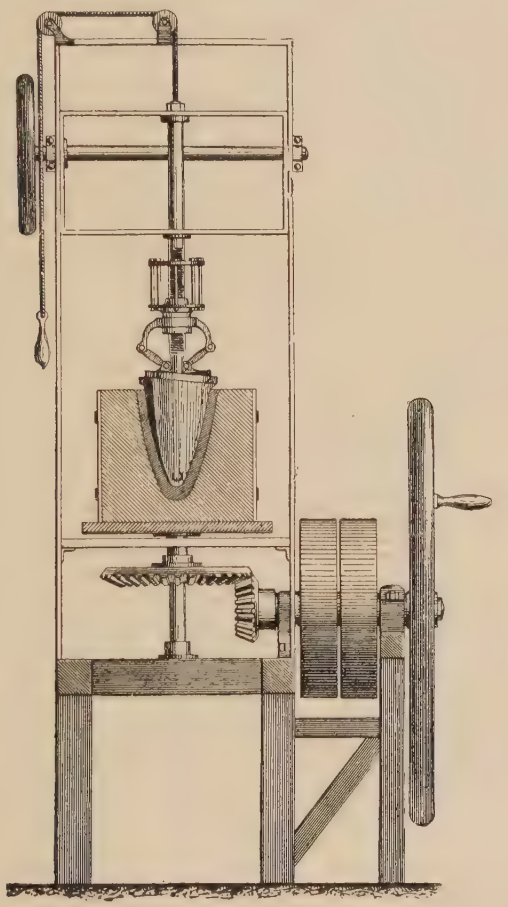

FIG. 278.—Machine for Moulding Crucibles.

the forms which will be mentioned further on when speaking about the manufacture of basic bricks.

The measuring and mixing being done in a dry state, the mass is put into a mixing machine, adding to it the proportion of water necessary for moulding; then the body is left for several days before being used.

The moulding is done by machine, because it is necessary

to compress the material. For this purpose a machine for moulding by turning is generally used, as shown in Fig. 278. The exterior mould of either plaster or cast iron, with a movable bottom, is placed on the table of a turning lathe set in motion by means of pulleys or a hand fly-wheel. The required quantity of the body having been put in the bottom of this mould, a chuck is lowered by means of a hand fly-wheel or of a rack, and this makes a rough form. Then, by working a lantern wheel, this chuck, which is in two pieces, is forced open, and compresses sideways the body against the outer mould. This compression is made stronger by the upper rim that carries the chuck, and prevents the body from going out at the top. When the chuck is open a last pressure is given by working the hand fly-wheel; then the chuck is taken out and the mould is emptied by taking away the movable bottom of the outer mould.

The crucibles when made are dried for some time in the air in the moulding shop, then placed in hot air stoves.

The drying being finished, the crucibles are heated in muffle kilns to a temperature of about 700° C. For this sometimes also round kilns with descending flames are used, being then charged in saggers.

The dimensions of plumbago crucibles are usually determined by the weight of the materials they are to contain, which varies from 10 to 150 lb.

The manufacture of carboniferous fireproof goods is localised in certain factories, some of which sell crucibles and others use them for their own purposes.

### 4. *Silicious Fireclay Goods.*

**242.** We have seen that silica is less refractory than alumina, but, as the ores of alumina are nearly always impure, while in nature fairly numerous beds of silica can be found which only contain traces of fluxes, it follows that fireproof ware which resists high temperatures can be made more economically with silica. Besides, these wares are decidedly acid, a property which is desirable in some metallurgic operations, and as they have a tendency to increase in volume in the kilns, by making arrange-

ments that take this swelling into account, very close and non-shifting masonry can be had.

The silicious fireproof goods are scarcely used except for the manufacture of bricks and blocks. The best known are those from Dinas, which have been made since 1822, with a quartzose sand found in the south of Wales, which contains 97 per cent. to 98 per cent. of silica. In order to make it stick together it is mixed with 1 per cent. to 1½ per cent. of lime diluted in water, then the mass is moulded in a press similar to those used for making ordinary brick of dry body. In many factories a hand press is simply used. The moulded bricks must be carefully and very well dried in artificial drying sheds, then they are burnt in round kilns with descending flames. The slow firing must be carried on very slowly, then the temperature is raised until it reaches 1,300° to 1,400° C. The cooling should be very slow; it is usually done without any air getting in, simply by the radiation from the kiln.

Emile Müller first introduced the manufacture of silicious bricks of the Dinas description on the Continent, and his example has since been followed by several manufacturers, especially in German factories.

In order that this manufacture should succeed it is necessary to powder the quartzeous sand, or rather pure silicious rocks, for nowhere has been found the natural sand of the quality of that used at Dinas. In this way is prepared, on the one hand, a fine impalpable powder, and, on the other hand, grains of ·0394 in. to ·2655 in., which are put through a sieve, and afterwards mixed together in suitable proportions. The best proportion for the mixture seems to be ⅓ of powder, ⅓ of grains from ·0294 in. to ·1181 in., and ⅓ of grains ·1181 in. to ·2655 in. The processes used for powdering the quartz have been described before; it is sufficient to add that if silicious rocks are used it is wise to calcine them first, so as to make them more easy to grind up. Afterwards 1½ per cent. of lime is added to the silica, and the making is continued as was described for Dinas bricks.

The part the lime plays does not only consist in giving it the plasticity necessary for moulding, because the very fine silica has a plasticity relatively sufficient for moulding bricks,

but it is used especially for giving a greater resistance to the burnt ware. At the high temperature at which it is burnt, it forms, in fact, a silicate of lime, which glues the silicious grains together. A larger proportion of lime would have the effect of making the ware more fusible. Lime has recently been advantageously replaced by chloride of calcium, dissolved in water. This salt decomposes with heat, the chlorine is given off, and the lime alone remains, but better divided up into the whole mass than when mixed direct.

It has been sought to replace the impalpable powder of a part of the silica, which is indispensable to obtain a certain plasticity, by adding clay instead. What has been said before (Art. 234) shows that this method ought to be condemned, because the refractory properties of the ware would thus be materially diminished.

The other things for sticking it together, silicate of soda, tar, treacle, etc., which have sometimes been praised up, do not give results to be compared with the good bricks from Dinas.

When very light bricks are wanted that will not have to resist a very high temperature, as, for example, those employed for the furnaces of locomotives or marine boilers, infusorial earths (Art. 47) can be used with advantage, which are mixed with a little fireclay. The rest of the manufacture is the same as that of argillaceous firebricks.

Lastly, it is advisable to mention silicious bricks made with the sand that has been used for polishing glass. This sand is moulded by means of presses, and the ware when made is dried, then burnt at a moderate temperature. It is glued together with the rather large proportion of glass which this sand contains. White ware is thus obtained imitating stone of a beautiful decorative appearance, but containing too much flux to be considered as a fireproof material.

### 5. *Basic Fireclay Goods.*

**243.** Basic fireclay goods owe their properties to the larger or smaller proportion of magnesia or lime that they contain. Magnesia seems slightly more fusible than alumina, but it can more easily be obtained nearly pure; it is less fusible than silica.

As to lime, that is the most refractory material known. These two bases may be employed either separately or mixed together. These different methods of manufacture will now be examined in succession.

*Goods with Magnesia.*—Magnesia may be obtained almost pure by extracting it from the mother water of the salt marshes or from the salt rocks. The latter contain sulphate of magnesia, and especially chloride of magnesium, which, when treated with milk of lime, leaves a deposit of hydrated magnesia. The lime can also be replaced by calcined dolomite, as suggested by M. Closson. Dolomite is a natural rock, somewhat widespread, which in a pure state is a double carbonate of lime and magnesia. In that case the reaction is the following :—

$$MgCl^2 + CaO,MgO = CaCl^2 + 2MgO.$$

The sediment of hydrated magnesia which is deposited is dried either in the sun or else in filter presses.

Magnesia can also be extracted from dolomite by M. Scheibler's process. For that purpose the dolomite is calcined to drive off the carbon, then dissolved in water; then a solution of treacle containing 10 per cent. to 15 per cent. of sugar is added to it. The mixture is stirred, and in a few minutes it is decomposed, a sugar of lime is formed that is soluble in water, while the hydrated magnesia is deposited and dried as already described. The sugared liquid is, in its turn, treated with carbonic acid, which is formed in the kiln used for decarbonating the dolomite. This precipitates the lime in the shape of a carbonate and cleanses the solution of sugar, which can then be used over again. This double reaction may be represented as follows :—

$$C^{12}H^{11}O^{11} + CaO,MgO = C^{12}H^{11}O^{11},CaO + MgO$$
$$C^{12}H^{11}O^{11},CaO + CO^2 = C^{12}H^{11}O^{11} + CaO,CO^2.$$

Whatever the method used, hydrated magnesia is obtained nearly pure, containing only about 2 per cent. of lime and 1 to 1½ per cent. of silica, oxide of iron and clay. When calcined above 400° to 500° C. it loses its water of combination as a hydrosilicate of alumina. Heated at a lower temperature, it may afterwards absorb the moisture of the air, and, by changing back into the hydrate, be of some kind of use again.

Calcined magnesia is usually mixed with some magnesia that has simply been dried, and thus a body is obtained which is sufficiently plastic to be moulded into bricks, and which has even been used for making crucibles or retorts. In this last case, however, it seems better to add a little very plastic clay to it. In order to obtain very resisting bricks, it is wise to make them with a press. The drying is first done in the open air, then in a heated drying shed; lastly, the burning, in which there is no difficulty, is done in the same way as for the ordinary fireproof goods.

This method of making bricks of magnesia is relatively a recent one; up to the present time most magnesia bricks were obtained by the help of carbonate of magnesia or giobertite, sometimes improperly called magnesite. The beds of giobertite are rather rare, the best known being those of Frankenstein (Silesia) and those in the Isle of Eubœa.

They commence by calcining the giobertite at a high temperature, so as to decarbonate it; then a certain quantity of non-calcined material is added to it, and a paste made which should be moulded by means of hydraulic presses. The plasticity, which is very slight, may be increased by moistening the mass with a solution of chloride of magnesium. After being dried in the air, it is burnt at a high temperature, but this is difficult on account of the considerable shrinkage which takes place in these goods when completely deprived of the carbon.

Magnesite has also been employed, that is a silicate of magnesia (Art. 35), but then goods that are relatively only fireproof are obtained.

*Goods with Magnesia and Lime.*—These goods are manufactured with magnesian limestones or dolomite. A mixture of lime and magnesia seems to possess the same fireproof qualities that each of these bases by itself has, but the addition of silica and alumina in the form of clay rapidly increases the fusibility. It seems, however, to be difficult to manufacture these limestones or dolomite without the mass containing some percentage of clay, either as it is found in it in nature, or added to it on purpose. This class of bricks, which are fairly economical as compared with the preceding ones, is only suitable for purposes

where it is indispensable to use basic materials, but without reaching very high temperatures.

They are manufactured by powdering the raw materials and changing them into a paste which is afterwards moulded in a press.

The drying is very slow, but there is no difficulty in it. The same cannot be said of the burning, because the shrinkage of the bricks is considerable, which is not lessened, as in bricks made of giobertite, by previously calcining a part of the material. According to M. Walrand, a body containing

| | |
|---|---|
| Silica | 5·00 |
| Alumina and oxide of iron | 5·00 |
| Lime | 28·00 |
| Magnesia | 18·00 |
| Water and carbonic acid | 44·00 |

makes bricks of a good quality.

*Goods Made with Lime.*—In opposition to magnesia, lime, even when well burnt, retains the property of being hydrated in air; therefore it is not possible to preserve goods made with lime except in an atmosphere that is absolutely dry. This condition, up to the present time, has only been fulfilled in electrical kilns, where the lime resists the formidable temperature of the voltaic arc. Except for this very limited use, for which the goods are manufactured on the spot, it is not possible to make bricks with lime except by combining it with alumina and oxide of iron. We know that it must not be thought of adding it to silica, as that makes silicates of lime, which are much more fusible than silicates of magnesia. The following composition, suggested by M. Walrand, would give good results:—

| | |
|---|---|
| Silica | 0·50 |
| Alumina and oxide of iron | 8·50 |
| Lime | 51·00 |
| Water and carbonic acid | 41·00 |

The manufacture of bricks with lime is done in the same way as those of dolomite, and has the same difficulties when being burnt.

### 6. *Fireclay Mortar* (*Pug.*).

**244.** The material which is used as mortar in fireproof masonry is usually furnished by the factories for fireproof goods at the same

time as the different materials which have been the subject of this chapter. Theoretically, this material is constituted of the same body as the goods were made of. The mixture, instead of being hydrated to make it into a paste, is, on the contrary, dried if necessary and put in sacks. Water is added to it only at the place and time when it is to be used.

We must, however, remark that the material, before being used in as thin a layer as possible, ought not to contain any opening material in coarse grains. For argillaceous goods, then, only fine sand or powdered grog can be employed. As this mortar shrinks in the kiln, it is also best to open it more than the body, and only to leave it as much plasticity as is strictly necessary, so that it can be used with a trowel.

The same observation applies to the mortar used for aluminous goods. For silicious goods or basic ones, it is sufficient to add a little clay to the body to give it a certain amount of plasticity.

The mortar is also used for stopping the cracks that may occur in the masonry or in crucibles and retorts. Ordinary mortar may be used in the first case, but in the second it is usually insufficient. All kinds of mortar that contain clay, however thin they may be, shrink to a certain degree, thus causing them to break off the parts repaired, and making this repairing very often only imaginary. In that case one can take advantage of the property of silica of swelling when submitted to a high temperature. The sand known in England and the United States by the name of ganister, the composition of which is given in Art. 47, has often been successfully used for this purpose.

A similar material can be artificially manufactured by using the sands made of powdered quartzeous rocks, to which is added about 10 per cent. of clay. This mixture is suitable for high temperatures; if that is not the case, some flux in the desired proportion must be added to it, so that the mortar should commence to vitrify, which would make it adhere to the fireproof goods.

### 7. *Tests for Fireclay Goods.*

**245.** In opposition to what we have seen in regard to the *terra cottas* for building purposes, the fireclay goods, up to the present time, have not been the object of any method of testing in general

use. The different factories where these wares are used have been satisfied with trying them in their kilns. Having regard to the very different conditions under which the fireproof goods are used, it may well be argued that this practical method is the only one that can give absolutely conclusive results. Yet we should no longer hide the fact that it is not completely satisfactory to the manufacturers of fireproof goods, who would like to be able to give their patrons the results of experiments that prove the quality of their ware. Lastly, from the point of view of general scientific interest, it would also be desirable for methods of testing to be adopted that would allow of the wares of various kinds being compared together.

The exact chemical analysis of the wares seems to be the first basis of comparison and the most important one. On account of its being so complicated, or of the quantities that have to be weighed being often so small, it could only be done in laboratories arranged for this kind of test and by competent chemists.

The measuring of the temperature which causes them to begin to vitrify or get out of shape, then that which makes them fuse, can be done in test kilns such as those described in Art. 151. As an apparatus of measurement, the most practicable seems at the present time to be Seger's tests. The material to be tested ought, by preference, to be put in the form of small triangular pyramids of ·394 in. sides and 1·18 in. high, in which it is easy to see and compare the changes of shape.

Concerning the measuring of the resistance to a rapid heating, up to the present nothing has been discovered better than to heat a test piece up to red heat and then plunge it into water. It is useless to insist on what such a method is worth.

The measuring of the coarseness of the grains, that of the expansion under the influence of a certain definite temperature, and that of the porosity would seem to us, on the other hand, as if they would give interesting and comparative results.

# CHAPTER XI.

## FAIENCES.

SUMMARY.—Classification.

SEC. 1. *So-called Varnished Faiences, with a Fusible Argillaceous Body:* Common Plumbiferous and Non-Plumbiferous Wares—Architectural Faiences—Encaustic Tiles—Stoves—Vases, Dishes and Decorative Objects.

SEC. 2. *So-called Enamelled Faiences, with a Fusible Argillaceous Calcareous Body:* Composition—Decoration—Stove Tiles, Panels, etc.

SEC. 3. *So-called Silicious Faiences, with a Fusible Silicious Body.*

SEC. 4. *So-called Pipeclay Faiences, with a slightly Fusible Argillaceous Calcareous Body.*

SEC. 5. *Faiences called Pebble Work, with a Fireproof Argillaceous Silicious Body.*

SEC. 6. *So-called Feldspathic Faiences, with a slightly Fusible Argillaceous Alkaline Body:* Composition—Preparation of the Bodies—Moulding—Drying—Burning—Setting and Placing in Saggers—Decoration.

General Arrangements of Faience Works.

**246. Classification.**—We have seen that faiences[1] are pottery of a permeable body, either white or coloured, but always covered with a glaze. It is the existence of this glaze which distinguishes them from the two other classes of pottery, the ordinary terra cottas and the fireproof terra cottas, which, with these, form the class of permeable ware.

We have already said that some potters do not admit of this classification (Art. 8), but that in this work we agree with the opinion of Deck: "In default of any other generic word, I call faience all ware of an earthy fracture (consequently permeable) covered over with an enamel".

It seems to us, in fact, to be difficult to class among terra cottas some varnished wares simply because the body of them is argillaceous and their glaze plumbiferous. In that case it would be necessary to reckon the pottery from Thun, and even

[1] From *Faenza*, a town in the Marches (Italy).

that by Bernard Palissy, as terra cottas. We know that it may appear odd to some people to call an enamelled brick or tile faience. But there are also stoneware and porcelain bricks and tiles; we do not then see why there should not be faience ones. It is certain that the meaning of the word faience has been considerably widened since the time when it was only used to denote Italian wares of the fifteenth and sixteenth century, and that it is a singular anachronism to apply it to the ware of the Persians. But, as Deck very well remarked, we have no other, and it is better, by accepting the clear and precise definition of that celebrated faience manufacturer, to get away from the confusion that had arisen in course of time from Brongniart's classification. The advantage of having a single word to denote all permeable wares with a glaze is especially felt if the French terminology is compared with that used in England and Germany. The English have no common term to denote all the classes of faience: *majolica, Delft ware, earthenware, flint ware, iron stone, queen's ware,* etc. It is the same in Germany, where *Steingut* denotes the fine faience of Brongniart, but where the other faiences all have a series of names: *Terra cotta, Majolika, Irden-geschirr,* etc., without, up to the present time, there being any general designation that is universally adopted.

The term faience having been adopted to designate all permeable wares covered with a glaze, we do not think that it is necessary to continue to call table ware, as Brongniart does, fine faience, and common faience the wares from Urbino, from Rouen, and consequently also the silicious faiences, the most beautiful productions of ceramic decoration. The intention of Brongniart was certainly not to cast a mark of disgrace on these latter wares, the adjectives fine and common only being applied by him to the bodies, which were entirely hidden by the glaze. But these words lead to a confusion that it is important to do away with. On the other hand, the distinction between fine and common bodies is based upon a difference of hardness, and we have already seen that the hardness should no longer be considered as a characteristic for distinguishing between them.

In speaking on the general principles of classifying the wares, we

said (Art. 3) that it is necessary "to be satisfied with defining precisely the principal kinds of ware and with grouping together those which, by the similarity of their properties, were the most like one another". Starting with this principle, it seems to us that we can distinguish at the present time six kinds of faience, forming sufficiently well-defined groups, in which can be classed nearly all wares of this order. The distinction between the different kinds is based upon the composition of the body, which includes to a certain degree that of the glaze. The classification adopted in this chapter is the following:—

1. *So-called Varnished Faiences, with a Fusible Argillaceous Body*, in which the fluxes, oxide of iron, alkalies, lime or magnesia are in a sufficiently large proportion to make the body fusible, without, however, any of them being in an overwhelming proportion. This body, which is always rather plastic, is the same as that used for a great number of terra cottas. It is formed by one or more clays, natural or washed, with the sole addition, if there is any need, of sand, or rarely of cement.

The glaze is usually plumbiferous, sometimes alkaline boracic.

The word "varnished," used to denote these faiences, seems to us altogether unsuitable, because it is applied to the glaze which must evidently be fusible, *because* the body is so also. This denomination, which we have used in default of another, is wrong in taking the consequence for the cause.

The principal varieties of this kind of faience are the following:

Common pottery;
Architectural faiences;
Encaustic tiles;
Stoves;
Vases, dishes and decorative objects.

2. *So-called Enamelled Faiences, with a Fusible Argillaceous Calcareous Body*, in which, in conjunction with a proportion, always rather small, of oxide of iron and alkalies, there is a large amount of lime. This body, which is moderately plastic, is formed either of a natural marl or of the mixture of a clay with a marl or with carbonate of lime. The glaze is usually stanniferous, sometimes plumbiferous.

The term "enamelled" denoting these faiences is also improper. Sometimes the word stanniferous is used; this is still worse,

because the tin is only to make it opaque, and its presence in a glaze gives no indication of the composition of the latter, and, still more, of that of the body. We have only used the word enamelled in default of another, and so as not to break through a terminology that has become consecrated by use.

3. *So-called Silicious Faiences, with a Fusible Silicious Body*, containing a little clay, a great deal of silica, and a good proportion of alkaline fluxes or limestone. This body, which is very slightly plastic, is at the present time composed of silica, with the addition of non-ferruginous plastic clay and lime, or alkalies of different kinds. The glaze is alkaline plumbiferous.

4. *So-called Pipeclay Faiences, with a slightly Fusible Argillaceous Calcareous Body*, formed of a mixture of white fireclay and a small proportion of carbonate of lime and marl. The body, which is decidedly plastic, needs a higher temperature for burning it than the preceding ones do. The glaze was formerly an alkaline plumbiferous one; now alkaline earthy bases and boracic acid are often added to it.

5. *Faiences called Pebble Work, with a Fireproof Argillaceous Silicious Body*, formed by the mixture of white fireclay and a large proportion of silica. The body, which is somewhat plastic, needs to be burnt at a high temperature. The glaze is plumbiferous, alkaline, alkaline earthy, boracic.

6. *So-called Feldspathic Faiences, with a slightly Fusible Argillaceous Alkaline Body.*—This somewhat plastic body is usually formed of a mixture of white refractory earth, kaolin, silica and an alkaline flux in the form of feldspar or pegmatite. The glaze is plumbiferous, alkaline, alkaline earthy, boracic.

It is impossible to include in this classification the so-called Oiron faiences that were mentioned in the historic part of this work (Art. 13). The body of them, when analysed by Salvetat, seemed to be composed of

| | |
|---|---|
| Silica . . . . . | 59·00 |
| Alumina . . . . . | 40·24 |
| | 99·24 |

with some traces of iron. The glaze is a plumbiferous varnish. The decoration was obtained entirely by slips incrusted in the

body. If the preceding analysis be taken as correct, one is surprised by the very large proportion of alumina, which would give so plastic a body that it would be very difficult to mould it; at least if to the almost pure white clay, which would serve as a base in the composition of the body, there is not mixed some grog made of the same clay. Brongniart puts the Oiron faiences among the so-called pipeclay ones, but the absence of lime in the body and of alkalies in the glaze prevents us from adopting this classification. This faience then constitutes a special kind, but considering the small number of potteries that make it (53) and the disappearance of this manufacture, it seemed to us unnecessary to put it into the general classification.

### I. *So-called Varnished Faiences, with a Fusible Argillaceous Body.*

247. **Common Plumbiferous Ware.**—Varnished plumbiferous pottery has been in general use for all domestic purposes from the twelfth to the fifteenth century. At the present time it is only used for vases, generally intended for cooking food. The body is either that of ordinary ware, or else composed of a more or less fusible clay, generally a ferruginous calcareous one, with the addition of grains of quartzeous sand or cement, the object of which is to make it less sensitive to the variations in temperature. What was said on the subject of fireproof bodies applies also to this ware. The resistance of heat, or rather of an unequal heating, is greater the larger the proportion of the thinning materials. In this direction the only limit is the necessity for keeping the body sufficiently plastic for it to be moulded.

This moulding is almost exclusively done by turning, fastening on the handles, spouts, or feet afterwards. They are easily dried near the moulding shops. When the drying is finished, the glaze can be put on the unburnt ware. If, on the other hand, the climate is not suitable for it, it is better to burn the body first, then to vitrify the glaze at a second burning. The latter, which is thin and transparent, is only for the purpose of making the body impermeable.

The glaze is a silicate of lead, which is more fusible in proportion as the amount of silica in it is less. The composition of it usually varies between

| | |
|---|---|
| Silica . . . . . | 28·8 |
| Oxide of lead . . . . . | 7·12 |

and

| | |
|---|---|
| Silica . . . . . | 44·7 |
| Oxide of lead . . . . . | 55·3 |

the first composition having the formula

$$PbO, 1\tfrac{1}{2}SiO^2,$$

and the second the formula

$$PbO, 3SiO^2.$$

Usually there is added to the glaze a certain quantity (from 5 per cent. to 20 per cent.) of clay, generally that employed for making the body being used for this purpose. This addition, which is to give the glaze a certain amount of plasticity, has the effect of lessening its fusibility, and may cause it to be necessary to modify the relative amounts of silica and oxide of lead. In any case it must be arranged that there should be at least 1½ equivalent of silica to 1 equivalent of base, if it is desirable not to risk there being some oxide of lead uncombined. If the proportion of silica is above 3 equivalents to 1 of the base the glaze usually becomes not fusible enough for this kind of ware.

The inside of vases is sometimes covered with a white glaze that is necessarily opaque. This is usually obtained by adding 10 per cent. to 15 per cent. of oxide of tin to the preceding varnish, and by, at the same time, reducing the proportion of silica so as not to alter the fusibility. The added clay ought in this case to be a white fireclay. In a general way these white enamels are rather difficult to get. Details of this subject will be found in the course of the work.

The glaze is generally applied by washing, sometimes by dipping, very seldom by dusting. The compound of lead employed is either red lead or galena for the commonest wares. The glaze is often colourless, or slightly coloured by the oxide of iron contained in the clay that is mixed with it. In that case the ware has a brighter colour than the body. Sometimes a certain percentage

of oxide of manganese (5 per cent. to 12 per cent.) is added to it so as to obtain a brown colour, or 2 per cent. to 3 per cent. of oxide of copper (scales of red copper), which gives it a green colour, more or less modified by the colour of the body which shows through.

It is still often burnt in horizontal kilns with one fireplace, but it would be more advantageous to use round kilns with descending flames. For large quantities, which are very rare, it would be better to use kilns with continuous firing with trenches, or else those with several burning spaces. The charging, whether for burning the body or the glaze, is done in bulk.

The manufacture of common ware is done in small local potteries, placed near the clay pits. The quality of the ware, that is to say, its resistance to firing, depends almost entirely on that of the clay that is used. There is no longer any reason for this manufacture, except the cheapness of the ware; also, however rudimentary it may be, it is useless to try and improve it, because then only dearer goods would be obtained, without the quality of them being comparable to that of other wares.

Among the common varnished wares may be classed also some pipes used for conveying liquids, the inside of the permeable body of which is covered over with a thin and transparent plumbiferous glaze. These pipes, moulded by turning or expression, which were formerly very much used, are at the present time almost everywhere replaced by stoneware pipes. The manufacture of them, in other respects, is the same as that of other common ware. The employment of a plumbiferous glaze presents certain dangers in pots intended for cooking food. When the temperature was not high enough to combine all the oxide of lead, or when the glaze does not contain enough silica (many compositions given in works on pottery are of this kind), this uncombined oxide of lead may be dissolved by the acids of the food and cause blood-poisoning.

The Board of Health in France has ordered the following method for testing whether the varnished wares are harmless: "Boil gently for half an hour in the doubtful pots some vinegar with the same quantity of water added to it, filling up the liquid as it evaporates and making the volume in proportion to the capacity of the pot (50 grammes of vinegar being sufficient for a

half-litre pot); let it cool, filter it and add to one part of the colourless solution some sulphuretted hydrogen dissolved in water, or pass a current of this gas through it. The presence of lead will be detected by a black precipitate or else by a brown colour. In another part of the solution some iodide of potassium would produce a yellow precipitate of iodide of lead." Manufacturers would do well themselves to try this experiment on certain of the least burnt of their ware before selling their goods, and thus avoid exposing themselves to very disagreeable consequences, independently of the trouble they would experience if they poisoned their fellow-citizens.

**248. Common Non-Plumbiferous Ware.**—The defect, happily a very rare one, which has just been pointed out is, however, serious enough to have caused numerous researches on the part of potters, for the purpose of replacing plumbiferous glazes by other compounds that do not contain lead. The problem is a very difficult one to solve, if at the same time the glaze must not be made too fusible and the price must not be increased out of proportion with the modern value of the ware.

If it is not intended to leave the lead out altogether, it can be partly replaced by a certain quantity of alkali, in such a way as to obtain a double silicate of lead and alkalies. In that case the alkalies are usually introduced in the form of silicate of soda or soluble glass, but soda or potash can be used direct. The chemical composition of these glazes may be represented by the formula

$$1 \left\{ \begin{matrix} PbO \\ K^2O \text{ or } N^2O \end{matrix} \right\} 1 \text{ to } 1\tfrac{1}{2} SiO^2.$$

On this principle, M. Constantin has suggested the following composition :—

| | |
|---|---|
| Silicate of soda in solution at 50° . . . . . | 100 |
| Red lead . . . . . | 25 |
| Silica (powdered quartz) . . . . . | 15 |

If it is advisable to leave the lead out entirely, on the one hand lime must be introduced into the glaze, so as to obtain a non-soluble glass with the alkalies, and, on the other hand, a part of the silica must be replaced by boracic acid, so as to increase the fusibility.

According to Seger, it would, besides, be necessary for the glaze to contain a certain proportion of alumina (clay) so that it should be

sufficiently transparent, the composition of the glaze being limited to the two following formulas :—

$$\left.\begin{matrix}0{\cdot}6K^2O \text{ or } Na^2O \\ 0{\cdot}4CaO\end{matrix}\right\} 0{\cdot}5Al^2O^3,\ 4SiO^2,\ 0{\cdot}5B^2O^3$$

and

$$\left.\begin{matrix}0{\cdot}2K^2O \text{ or } Na^2O \\ 0{\cdot}8CaO\end{matrix}\right\} 0{\cdot}6Al^2O^3,\ 5SiO^2,\ 1B^2O^3$$

which correspond approximately to the following centesimal proportions :—

| | | |
|---|---|---|
| Silica . . . . . | 60·5 | 58·6 |
| Boracic Acid . . . . . | 11·5 | 18·0 |
| Alumina . . . . . | 13·0 | 12·0 |
| Lime . . . . . | 5·6 | 9·0 |
| Alkalies . . . . . | 9·4 | 2·4 |
| | 100·0 | 100·0 |

The relative amount of lime and alkalies depends on the composition of the body, the alkaline glazes having to be applied to silicious bodies and the calcareous glazes to aluminous bodies. On the other hand, M. Constantin has suggested for the glaze without the addition of clay the following composition :—

| | |
|---|---|
| Silicate of soda in solution at 50° . . . . . | 100 |
| Carbonate of lime . . . . . | 15 |
| Silica (powdered quartz) . . . . . | 15 |
| Borax . . . . . | 10 |

A white glaze can be obtained by adding to the most fusible glaze from 10 per cent. to 12 per cent. of oxide of tin if the body is slightly coloured, and from 12 per cent. to 15 per cent. for ferruginous bodies. If, on account of this mixture, the fusibility becomes too weak, it is sufficient to increase the proportion of boracic acid slightly.

Some glaze merchants sell leadless glazes, the composition of which they keep more or less secret, but it does not seem as if these compounds, which, besides, contain all the substances already mentioned, could be applied indiscriminately to all kinds of body, as the plumbiferous glazes can, by the simple addition of silica or clay.

It has also sometimes been suggested to introduce the salts of baryta—heavy spar or witherite—into these glazes, but these substances present difficulties in use that are not very easy to overcome in the factories for common ware, which are always rather primitive.

**249. Architectural Faiences.**—Bricks, tiles, paving tiles, the architectural terra cottas of which we spoke in Chapter IX., may be covered over with glazes. As we have seen in the historical survey of pottery, this use of glaze dates back to the remotest antiquity. After having been invented by the Egyptians and Persians, who, however, made use of bodies which were more silicious than those of which we are now speaking and of which we shall speak later on (Art. 256), it was lost, and came into favour again in the East in the tenth century, and in Europe in the twelfth or thirteenth century, thanks to the employment of plumbiferous glazes. Yet this beautiful manufacture almost entirely disappeared after the sixteenth century, to reappear, but very slightly, in the course of the nineteenth century. We must, however, remark that it has always been much favoured in the far East. At the present time, the body of the architectural faiences is nearly always formed of a fusible clay; it is only rarely, and then for small objects, that use is made of one of the bodies for faience which will be described in the course of this chapter. All the bodies for terra cottas cannot receive glazes. Independently of the agreement which is indispensable between the glaze and the body, it is absolutely necessary that the latter should have a fairly smooth surface and not be too porous. These defects, however, can be at least partially corrected by smoothing the body after it has been moulded or by covering it over with thin slip.

The composition of the glazes and the manner of putting them on naturally depends on the composition of the body, on the colouring of it, and also on that of the glaze.

If the body is inclined to orange or red, a transparent plumbiferous glaze gives it a more or less intense red colour. By adding to this glaze from 5 per cent. to 8 per cent. of oxide of manganese, darker or lighter brown colours are obtained. A mixture of the oxides of iron and manganese, with a touch of cobalt, makes black. All the other colours can only be obtained on this body by means of slips or opaque glazes.

With yellowish bodies the series of transparent colours is much richer. Silicate of lead alone gives yellow. The mixture of that with oxide of iron or manganese produces the preceding various red and brown colours. Besides, green can easily be obtained by means of oxide of copper, and blue with oxide

of cobalt. There are scarcely any except quite light colours and white which need be opaque.

Lastly, it is only quite exceptionally that a body already sufficiently white has to be decorated, as with a colourless glaze white can be produced. A light yellowish tint, however, can be hidden by a glaze containing a little cobalt.

This being settled, we see that the decoration in colours of architectural faience resolves itself into three points:—

1. The employment of a transparent glaze on a body covered by coloured slip.

2. The employment of transparent coloured glazes.

3. The employment of an opaque, white glaze, which can be slightly coloured for light tones.

There are special conditions of manufacture, colour and shape of the wares which have to decide as to the use of slips or coloured glazes; it is impossible to give any rule as to that question.

The colourless transparent glazes are always plumbiferous; the composition of them is usually one equivalent of oxide of lead to 2, 2·5, or 3 of silica, that is to say, that it usually varies from 60 per cent. to 55 per cent. of oxide of lead to 40 per cent. or 45 per cent. of silica. The most silicious bodies are used with the most plumbiferous varnishes.

The coloured glazes are generally formed of the preceding plumbiferous glaze, with the addition of colouring oxides in the proportion of a half to five per cent., according to the shade that is required. This quantity having been added to the oxide of lead, the amount of silica is slightly varied, so as to obtain glazes that are equally fusible.

In order to obtain certain colours it is necessary, as we saw in Chapter VIII., to introduce some alkalies into the glaze. In that case a part of the oxide of lead is replaced by alkali, the proportion in no case being allowed to be above one equivalent of lead for one of alkali: the chemical composition in that extreme case being

$$\left.\begin{matrix} 0{\cdot}5PbO \\ 0{\cdot}5K^2O \text{ or } NaO \end{matrix}\right\} 3SiO^2.$$

On the other hand, it is not wise to make the amount of

silica fall below $2\frac{1}{2}$ equivalents. The introduction of the colouring oxides modifies the fusibility a little, but this can be corrected by varying the proportion of silica with the preceding limits. If, in spite of this correction, the glaze was still too fusible, the proportion of alkali would be lowered, and if that cannot be done because of the colour that is wanted, then in place of the lead a little lime or oxide of zinc would be added, as these are much more refractory.

As to boracic glazes, they are scarcely ever employed in the glazes for architectural faience, because the degree of fusibility required can always be more economically obtained with oxide of lead.

Opaque white glazes are more difficult to get, because the introduction of the elements to make them opaque has the effect of lessening the fusibility. If the body contains a rather large proportion of lime, the white enamel for enamelled faience, of which we shall speak later on, can be made use of. If such is not the case, and if the body is slightly coloured, sometimes an enamel can be used composed of 60 per cent. of oxide of lead and 40 per cent. of silica, with the addition of 10 per cent. to 12 per cent. of oxide of tin. For highly coloured bodies this enamel is not opaque enough, and besides it is often too refractory. In these two cases we must then resort to the use of boracic acid as a flux, by partially substituting this for the silica. Enamels of this kind can be represented by the formula

$$\left\{\begin{matrix}0{\cdot}7PbO\\0{\cdot}3CaO\end{matrix}\right\}1{\cdot}5SiO^2,0{\cdot}5B^2O^3 + 10 \text{ per cent. to } 12 \text{ per cent. } SnO^2,$$

which is only given by way of an example, all the proportions being subject to variation, according to the nature of the body and the degree of fusibility to be obtained.

Further, the whole or part of the oxide of lead can be replaced by alkali, but then the amount of silica must be increased, and then they resemble the glazes used for the common non-plumbiferous wares, of which we have just spoken.

The glazing is done by different methods. For bricks, which are always glazed on one or two faces only, it is generally done by immersion. For tiles or paving tiles the upper face

is sprayed. Lastly, other kinds of architectural faience are glazed by one or other method, at least, if one is not obliged to put it on with a brush, which is naturally compulsory when the pieces are many-coloured. When the goods are round, this application with a brush can be more easily done by turning them on a wheel, the brush being moved in height only when a whole turn has been accomplished.

Generally, it is applied to the unburnt dry body; for some more delicate objects it is preferable, however, to apply the glaze to the burnt body.

The burning may sometimes be in the continuous kilns used in tile works or brickfields, especially if they are heated by gas, and if the glazed or enamelled parts are carefully protected by an appropriate placing. However, it is generally preferable to burn architectural faience either in a muffle or else placed in saggers in round, intermittent kilns. The atmosphere of the kilns, however, ought always to be oxidising, and the length of the hard firing should be short enough to prevent too great a volatilisation of the oxide of lead, or of the boracic acid.

Besides, all the methods which were mentioned in Chapter VIII., and especially gilding, can be used for decorating architectural faience. In some cases they have tried to lessen the shine of the glaze by diminishing its fusibility, especially by adding to it a larger proportion of silica. Vitrification is then not complete, and the surface remains more or less dull, without, however, it having the absolutely dull look of the slipped ware.

There now remains to be examined one question, which has raised many discussions, *viz.*, that of the resistance of architectural faience to the weather, and especially to frost. First, it is quite evident that the body must fulfil the conditions of resistance of which mention was made when speaking of terra cotta (Art. 230), and that the least burnt bodies must not be taken and covered over with a glaze, as there has been an attempt sometimes to do.

If, then, a body that is perfectly resisting is taken, it is easy to see that the presence of a glaze has the effect rather of diminishing the resistance than of increasing it. The body

being saturated with water, if it is subjected to frost, the ice which is formed in the pores exercises on the whole interior surface of the glaze a pressure which tends to detach it, or at least, to make it crack off in scales. To remedy this defect, which may become serious, it is absolutely necessary to obtain a close union between the body and the glaze. This latter ought to penetrate sufficiently deeply into the pores of the body, and not simply form a layer on the surface. This object is obtained by giving the glaze a composition which allows it to harmonise with the body, and even to act upon it chemically. Thus a strongly alkaline glaze would adhere better to a silicious body than to an aluminous body, in consequence of the combination of the alkalies of the glaze with the silica of the body. The opposite effect is more difficult to get, because an excess of silica in the glaze, which would be sufficient to act upon a basic body, would make this glaze too hard to vitrify. On the other hand, it is necessary, in order to obtain good ware, that the vitrification should be complete and sufficiently prolonged to allow of the glaze penetrating well into the body, and to give time for the chemical actions to take place.

Faience manufactured under these conditions would resist all weathers, as has been proved by numerous examples of faience of the Middle Ages, employed in the outsides of buildings, which have remained intact up to the present day.

Nevertheless, it is prudent to place the faience in such a way that the surfaces which are not enamelled should not be too much exposed so as to absorb the water. This condition is nearly always easy to be accomplished in walls; as to roofs, it is sufficient not to give them too little slope. These varnished or enamelled roofs, having also a decorative purpose, it is always best, so as to make the decoration effective, to give them a rather steep inclination.

**250. Encaustic Tiles.**—Encaustic tiles deserve a place to themselves among architectural faiences, because of the great development which has taken place in the manufacture of them in the Middle Ages, and on account of certain specialities in the making of them. The most ancient examples of tiles of this kind that we possess date from the twelfth century; they were very much in vogue in

France, England and Flanders for the paving of churches and castles in the thirteenth, fourteenth and fifteenth centuries. Then they disappeared in the sixteenth, to be replaced by enamelled faience paving tiles. This manufacture has since been revived, especially in England, but although the modern ware may be more resisting than the ancient, it is scarcely probable that the use of them will spread, on account of the competition there is between them and stoneware inlaid tiles.

The manufacture of encaustic paving tiles includes the following different operations:—

1. Moulding the tiles by hand with an argillaceous body.

2. Stamping them in hollows by means of a block on the upper surface of the tile when slightly dried, in the shape of some design.

3. Filling the hollows thus obtained with a somewhat liquid body of a different colour to that of the tile, and the scraping of the surface by means of a metallic straight-edge.

4. Beating the stiffened tiles to harden their surface.

5. Glazing the upper surface of the dry tile by spraying it with a plumbic glaze.

6. Burning them in muffles or saggers.

These paving tiles are usually square, of small size, from ·79 in. to 1·18 in. thick. The ancient tiles were sometimes of various shapes, according to the design they were to reproduce. The depth of the stamped hollows varies from 1·18 in. to 1·97 in.

The previous method of making them may be simplified by moulding them in a press. In that case a metallic mould is used, in the bottom of which is placed a little piece of plaster with a projection equal to that of the hollow that is required. A rough cake of fine body is put into it, which is intended to form the surface; then a thicker slab of coarser body is put over it, after which a stroke is given with the press to mould and weld the whole together. The employing of two different bodies is for the purpose of economising the more costly fine body. The rest of the manufacture takes place as we have just said.

The tiles are generally yellow, orange, red, brown or black. The slips, also, can be coloured green or blue by copper, chrome and cobalt. As these slips are put on with a more liquid body

than that of the tile, they would shrink more and become detached if the precaution were not taken of putting more thinning material into the composition of them. As to the glaze, it is a silicate of lead and does not differ from those already described for the preceding ware.

**251. Stoves.**—Nearly all the stoves manufactured at the present time have an argillaceous-calcareous body. We will give more details about this manufacture in the following paragraph. Yet the argillaceous bodies, when suitably thinned, can be employed for this purpose, contrary to the general opinion even of potters. All the stoves manufactured in Germany, Switzerland, and Alsace before the sixteenth century, made of tiles fastened together, which were often of large dimensions, were made in glazed faience. It was only at the end of the sixteenth century that Hirchvogel introduced at Nuremberg the manufacture of stoves in enamelled faience.

The difficulty consists in finding a body that well resists a rapid and often uneven heating without cracking, and which, at the same time, can be covered with a glaze which will not start. One generally goes from one defect to the other without finding a true medium. As the resistance to heat is finally more important than the decoration, the result is that the glaze is almost always crackled.

Good results, however, can be obtained by proceeding as follows: A large enough proportion of sand with a medium coarse grain is mixed with the clay in such a way as to obtain a body similar to that of fireproof goods, but grog must not be added to it, as is done for argillaceous-calcareous bodies. The tiles when made are burnt, then covered with slip of a plastic clay thinned with fine sand or ground quartz, but not powdered. When the slip is dry the glaze is sprayed on, and a second burning takes place. If the stove is to be white, then a white clay is used as a slip, because it is difficult, if not impossible, to employ an opaque enamel similar to those used for architectural faience.

**252. Vases, Dishes and Decorative Objects.**—The use of plumbiferous glazes for vases, dishes, and other decorative articles of furniture was known to the Egyptians, as is proved

by the pottery found in the hypogea, and which has been wrongly called by the name of Egyptian porcelain. The modern archæological discoveries have shown that the plumbiferous glazes have never ceased to be known, but that for reasons unknown the manufacture of them has never been developed. We must wait until the twelfth century to see the glazed pottery become the object of regular manufacture in Italy, whence it spread in the thirteenth century to France and Germany.

The body was always coloured, consequently the colours introduced into the transparent glaze could only give yellow (this only on light bodies), red, brown and green. On the other hand, the decorative moulding of the body consisted of reliefs, modelled by hand, or stamped separately and put on, and of features carved out or hollowed into the body while still plastic. The manufactories of Beauvais have long been renowned for this kind of ware.

In the fifteenth century the use of slips furnished another means of decoration. We know that slips were known by the Greeks and Romans, but they appear to have fallen into oblivion, to be used afresh in Italy, whence, in the same way as plumbiferous varnish, they spread over the whole of Europe.

We have already said that this manufacture disappeared in the sixteenth century, or at least it has no longer been used except for the production of common ware. Yet they continued to make at Thun, in Switzerland, and in the Black Forest some wares which have been the fashion again for a time, and the decoration of which is done on a body that has first been covered with a general slip, either brown or white, by putting coloured slips upon it by means of a pot with a thread-like spout, which allows them to fall out drop by drop. This process has been called by the name of imitation sugar work (Art. 190). It is usually finished off with a brush in such a way as to form flowers, leaves, or other simple motives of ornamentation. The wares are afterwards heated at a low temperature to fix the slip well, then covered with a plumbiferous varnish by watering it or by immersion.

Some potters have classed the wares by Bernard Palissy among enamelled faience; it seems impossible to us to agree with their opinion. Doubtless the body used by Palissy is very slightly coloured, which makes it different from other ancient varnished faience, but the following composition given by Brongniart, classes it among the argillaceous non-calcareous bodies :—

| | |
|---|---|
| Silica | 67·50 |
| Alumina | 28·51 |
| Oxide of iron | 2·05 |
| Lime | 1·52 |
| Magnesia | 0 |
| Alkalies | not measured. |

The glaze, besides, is distinctly plumbiferous; if it contains a little tin, that can only be, according to Deck's opinion, accidental, and not for making the coloured glazes opaque, because Palissy has not precisely used a relatively white body, except to obtain a white colour with a transparent varnish.

The moulding of the ornaments, leaves, feathers, various animals, must be done by moulding the pieces themselves and by sticking the pieces thus obtained on to the vases or on to the dishes.

The colours of the glaze are a decided yellow and yellow brown, doubtless obtained with ochres, an indigo blue from cobalt, a greyish blue, an emerald green from copper, a yellow green from copper and ochre, a violet from manganese, and a violet brown from manganese and ochre.

Bernard Palissy's faiences have often been imitated, but for this purpose argillaceous-calcareous bodies have been used in preference to stanniferous glazes.

The artistic decoration of glazed faiences has been very much developed of later years. Potteries that have become important ones have made them their speciality.

### 2. *So-called Enamelled Faiences, with a Fusible Argillaceous Calcareous Body.*

**253. Composition.**—Enamelled faiences have been used for table ware and for all decorative and show pieces from the sixteenth to the eighteenth century. At the present time it is no longer used

except to make imitation Moorish, Italian or French faiences, and for the manufacture of stove tiles.

The following, according to Brongniart, is the composition of the body of a certain number of these faiences :—

| | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Carbonic Acid and Loss. |
|---|---|---|---|---|---|---|
| Persian faience (of the 14th to 16th century) . . . | 48·54 | 12·05 | 3·14 | 19·25 | 0·30 | 16·72 |
| Hispano-moresque faience . . | 46·04 | 18·45 | 3·64 | 17·64 | 0·87 | 13·96 |
| Hispano-moresque faience from Manises . . . . | 54·71 | 18·80 | 2·20 | 19·69 | tr. | 4·60 |
| Luca della Robbia faience . . | 49·65 | 15·50 | 3·70 | 22·40 | 0·17 | 8·58 |
| Nevers faience . . . . | 56·49 | 19·22 | 2·12 | 14·96 | 0·71 | 6·50 |
| Rouen faience . . . . | 47·96 | 15·02 | 4·07 | 20·24 | 0·44 | 12·27 |
| Delft faience . . . . | 49·07 | 16·19 | 2·82 | 18·01 | 0·82 | 13·09 |

The iron oxide and carbonic acid and losses include the alkalies which unfortunately have not been measured, and the carbonic acid given off from the carbonate of lime which is not decomposed on account of the insufficient temperature for burning them.

In these bodies the proportion of lime varies from 15 per cent. to 22 per cent., about 20 per cent. being the average, which corresponds to 35 per cent. or 36 per cent. of carbonate of lime. This large amount of lime is only allowable on account of the slight burning, one part only of the carbonate having been decomposed, and the other not having acted as a flux, but simply as a thinning material. With the higher temperatures that are used at the present time for burning the bodies it is best to slightly lessen the proportion of lime. If we imagine all the carbonic acid left out, the medium for the amount of lime in the preceding bodies would be from 22 per cent. to 23 per cent., while now the limits are 13 per cent. to 16 per cent. Below that the stanniferous enamel has a tendency to start, and above that the body behaves badly when burnt and absorbs the plumbiferous glazes, that can also be used to decorate it.

Deck puts down for faience in imitation of Palissy ware a composition which would give a body containing from 65 per cent. to 66 per cent. of silica, 14 per cent. to 15 per cent. of alumina, and 19 per cent. to 20 per cent. of lime. We think that it would be

better to lessen the proportion of lime and to keep to the bodies of which the composition would vary between the following limits :—

| | |
|---|---|
| Silica | 60 to 65 |
| Alumina | 13 „ 20 |
| Oxide of iron | 2 „ 4 |
| Lime | 13 „ 16 |
| Alkalies | 2 „ 4 |

These bodies, at first reddish-yellow when they are burnt at a low temperature, become a slightly yellowish white when they have been burnt enough to decompose the carbonates.

All the ancient bodies for enamelled faience and the most of the new ones are entirely covered over with an opaque white glaze, which forms the background for the decoration.

The following are some different compositions for this enamel given by Brongniart and Bastenaire-Daudenart :—

| | | | | | |
|---|---|---|---|---|---|
| Calcine composed of :— | | | | | |
| Oxide of tin | 23 | 18 | 20 | 16 | 23 |
| Oxide of lead | 77 | 82 | 80 | 84 | 77 |
| | 100 | 100 | 100 | 100 | 100 |
| Calcine | 45 | 45 | 46 | 45 | 44 |
| Oxide of lead | 2 | — | — | — | — |
| Sand | 45 | 45 | 45 | 47 | 44 |
| Alicante soda | 3 | 3 | — | — | 1 |
| Sea salt | 5 | 7 | 9 | 8 | 11 |
| | 100 | 100 | 100 | 100 | 100 |

In these compositions it must be noticed that Alicante soda contains only about a third of carbonate of soda and that its action is consequently almost nothing; it would seem to be added in the same way as the tartar from wine used by the Italians, only so as to facilitate the fritting of the enamel.

Under these conditions the following composition can be taken for these glazes :—

| | | |
|---|---|---|
| Silica | | 45 |
| Calcine | Oxide of lead | 36 |
| | Oxide of tin | 10 |
| Sea salt | | 9 |
| | | 100 |

This composition, when burnt, gives an enamel corresponding somewhat to the formula :—

$$\left.\begin{matrix}0{\cdot}25Na^2O \\ 0{\cdot}75PbO\end{matrix}\right\} 3{\cdot}5SiO^2 + 0{\cdot}8SnO^2.$$

It is wise to frit the sea salt and the silica first, then to add the calcine and to smelt them. If, as is often done, the whole is fritted together, there is a fear that the salt will not be completely decomposed.

254. **Decoration.**—The special methods of making dishes, vases and decorative objects in faience will be examined at the end of this chapter; at present we shall only discuss the special methods for decorating enamelled faience.

The white enamel, of which the composition has just been pointed out, may be coloured by the addition of 3 per cent. to 10 per cent. of colouring oxides. For example, yellow is obtained by 9 per cent. of antimoniate of lead, blue with 5 per cent. of oxide of cobalt, green with 5 per cent. of protoxide of copper, violet with 4 per cent. of oxide of manganese, etc.

The body having been burnt at a temperature sufficiently high to decompose the carbonates (1,000° to 1,200° C.), the enamel is applied either by immersion or watering, then it is left to dry. The decoration can then be done by two methods: either the colours are put on the unburnt enamel and the manufacture is finished by a second burning, or the enamel is first burnt, and then decorated, the colours being afterwards fixed by a third heating.

The first method, called *painting for hard firing on raw enamel*, has been almost the only one used in the manufacture of the Italian, French and Dutch faiences from the fifteenth to the eighteenth century. We have seen, in Art. 193, that this method presents great difficulties, on account of the friability of the raw enamel, but that, on the other hand, for painted decorations, it gives deeper tones, becoming more embodied in the glaze. The vitrifiable colours used are generally plumbiferous, sometimes alkaline-plumbiferous. In Italy and Holland it was the custom to sprinkle the raw enamel with a second alkaline-plumbiferous glaze, which allowed of the employment of alkaline vitrifiable colours and gave a greater shine to the ware.

The *painting on burnt enamel* has been employed since the beginning of the eighteenth century, by Hannong and all the potters who were disciples of the Strassburg school. This

method has usually been employed since, the decoration being easily done by means of vitrifiable colours. Transparent coloured glazes can also be made use of by surrounding the different enamels with a black outline, that is to say, by making use of cloisonné enamels (Art. 192).

The two preceding methods of decoration are based upon the use of a white stanniferous enamel as a background, hiding the colour and defects of the body. This is why the name of stanniferous faience has been given to this class of ware. But as, at the present time, it is easy to obtain very slightly coloured argillaceous calcareous bodies, these can be covered with transparent glazes of more varied colours, as we said when speaking of Bernard Palissy's faience. The calcareous composition of the body then has the advantage of allowing at the same time of the use of transparent and opaque enamels for light tones, and especially for white, which is so difficult to obtain with argillaceous bodies.

**255. Stove Tiles, Panels, etc.**—We have seen that stove tiles, panels, and in a general way the faiences that have to bear an uneven heating, must be made of a body somewhat like that for fireproof terra cottas, that is to say, one formed by the mixture of a clay and quartzeous sand or grog. Unfortunately, the porous mass thus obtained cannot be covered with glaze. The surface of it must be made more compact by slip of the same clay, with the addition of some fine sand. Then it can be covered with a plumbiferous varnish, but not with an opaque enamel. This latter can only be fixed without cracking to a calcareous body.

Thus, on the one hand, in order to resist heating, an argillaceous, porous, coarse body is needed; and, on the other hand, for the glaze, a compact calcareous fine body is required. It is somewhat difficult to find the exact medium between these contradictory conditions. At first sight it would seem as if a solution might be found by making the tiles with a coarse fireproof body, which would be covered with a slip of fine calcareous body. But the difficulty is simply shifted; there being no agreement between the two bodies, the slip would start.

At the present time there are two ways of solving this

difficulty: by taking a moderately calcareous body, opened by means of sand and grog, and covering it, by dipping or brushing, with a slip made of the same body, only finer, that is to say, thinned only with fine sand; or else by using a kind of body that has a medium composition and texture.

As the physical texture plays as important a part as the composition, it is impossible to give a definite type of body, so we must content ourselves with setting down the following general rules. The amount of carbonate of lime ought to vary from 10 per cent. to 14 per cent., below which the enamel starts; above it the body splits. The proportion of 14 per cent. corresponds to a body containing a little oxide of iron, it may be from 1 per cent. to 2 per cent., while the proportion of 10 per cent. is applicable to the bodies containing from 5 per cent. to 6 per cent. of it. The proportion of alumina ought to be as much reduced as possible, so as only to leave the plasticity that is strictly necessary for moulding, which, with the relative plasticity of carbonate of lime being given, usually corresponds to a proportion of 12 per cent. to 14 per cent.

According to Barral's analysis, the ancient body used by Pichenot was composed of—

| | |
|---|---|
| Silica | 56·3 to 55·4 |
| Alumina | 29·2 ,, 26·6 |
| Oxide of iron | 0·9 ,, 1·3 |
| Lime | 14·7 ,, 13·2 |

and formed by the mixing of—

| | |
|---|---|
| Plastic clay | 23 parts |
| Marl | 25 ,, |
| Sand | 12 ,, |
| Fireclay cement | 37 ,, |

The composition of the fireclay cement being set down as evidently rather aluminous, we see that about half the alumina must be in the cement, that is to say, in the state of an anti-plastic material.

In Germany at the present time for the manufacture of stove tiles Velten clay is much used, the composition of which, according to Seger, was the following:—

| | |
|---|---|
| Silica | 47·86 to 43·48 |
| Alumina | 11·90 „ 10·46 |
| Oxide of iron | 5·18 „ 5·10 |
| Lime | 18·68 „ 14·96 |
| Magnesia | 1·71 „ 1·42 |
| Alkalies | 4·00 „ 3·66 |
| Water and carbonic acid | 16·98 „ 15·08 |

This clay, tested by washing with M. Schöne's apparatus (Art. 52), gives :—

| | |
|---|---|
| Grains of less than ·0004 in. | 73·48 |
| „ „ ·0004 in. to ·0010 in. | 4·02 |
| „ „ ·0010 in. „ ·0015 in. | 8·28 |
| „ „ ·0015 in. „ ·0078 in. | 14·00 |
| Grains of more than ·0078 in. | 0·22 |

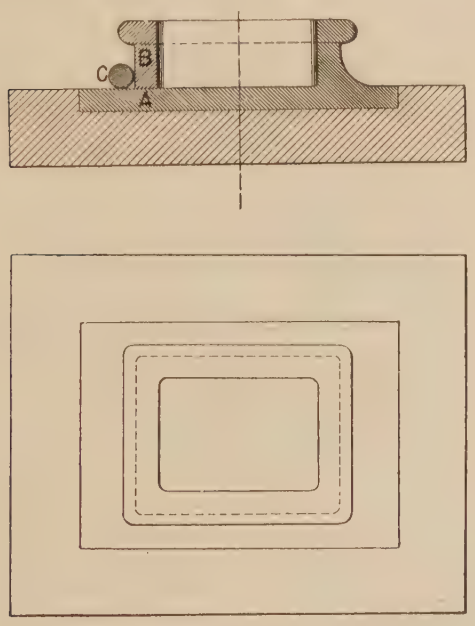


Fig. 279.—Moulding of Stove Tiles.

The preparation of the bodies is by first sorting the clay, then proceeding as described for argillaceous fireproof bodies. The making is always by moulding by hand, generally in plaster moulds, by putting into them a rough shape, obtained by cutting from a block of the body a slab of the required dimensions. In this way panels having as much as 24 and even 30 inches square on the surface can be obtained.

For stove tiles the moulding is more complicated. This is how it is done in Germany, the country where the most important factories for this ware are situated.

In a plaster mould (Fig. 279) they first begin by making a plaque (A), as we have just described; then a column of body (B) is put on it, this is obtained by expression; to this a rectangular form with rounded corners is given by joining it to itself, and then to the plaque. When this is done, a round roll (C) is added to it outside, which is flattened in the hand in such a way as to make a *curve* that strengthens the previous welding.

The angle tiles or corners are moulded in the same manner, but in that case the plaster mould must be in two pieces (Fig. 280), so that they can be taken out of the mould.

The preceding manual operations may be simplified by using the machine made by M. Schlickeysen, shown in Fig. 281. After having put a flat cake of body (A) into the mould,

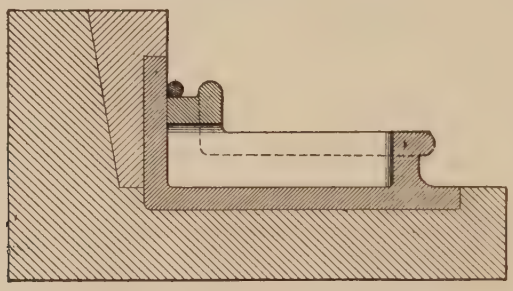

Fig. 280.—Moulding of Stove Tiles.

as we have just said, and the shaped column (B), a chuck is lowered, that has the shape of the interior hollow of the tile; then, by means of two lateral screws, a pressure is exerted in such a way as to weld the whole. It has been tried, but up to the present without success, to mould the tiles direct in the press without a rough form first.

The drying ought to be done very slowly, but on account of the unsymmetrical shape of the tile the surface has always a tendency to bulge. So, when the body is dried, it is necessary to straighten it by striking it on a marble slab. In some factories it is levelled on a millstone. For corner tiles two marble slabs, fixed together at right angles, are used.

They are charged open, two tiles being put against each other, the faces that show being in contact. The burning does

not present any difficulties, but it is necessary to straighten the burnt pieces a second time. This operation is done on a large horizontal millstone, usually of cast iron, covered over with polishing sand, with the addition of water The tiles are placed face downwards on the millstone, turning them about from time to time by hand, or by using a little special arrangement for this purpose.

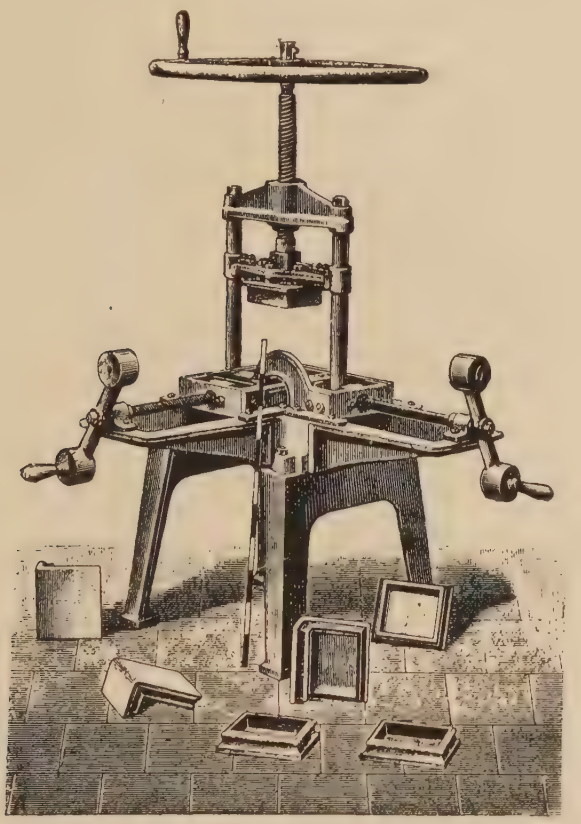

Fig. 281.—Machine for Moulding Stove Tiles.

The glaze is applied by pouring, and the burning is in muffle kilns, or, better still, in saggers, as we shall see further on.

The composition of the glaze is that which has been already mentioned, yet at the present time in Germany enamels having a larger amount of alkali are used. The following are two results of the analyses of vitrified glazes, the former, the older one, being from the house of Fleiner, in Berlin, who

made a speciality of the sale of enamels for stove tiles, and the second being of recent manufacture:—

| | | |
|---|---|---|
| Silica | 46·70 | 46·20 |
| Oxide of lead | 26·75 | 32·12 |
| Oxide of tin | 14·00 | 9·24 |
| Alumina | 4·90 | 4·24 |
| Lime | 1·36 | 2·58 |
| Potash | 1·94 | 0·67 |
| Soda | 4·35 | 4·95 |
| | 100·00 | 100·00 |

We do not know the mixtures which were used for making these glazes, but it seems that they are composed of limestone, sea salt, and a feldspathic sand, or quartzeous sand and feldspar. They correspond to the following formulas:—

$$\left.\begin{array}{l}0{\cdot}53PbO\\0{\cdot}06CaO\\0{\cdot}10K^2O\\0{\cdot}31Na^2O\end{array}\right\}0{\cdot}21Al^2O^3,\ 3{\cdot}43SiO^2 + 0{\cdot}79SnO^2$$

$$\left.\begin{array}{l}0.56PbO\\0{\cdot}10CaO\\0{\cdot}03K^2O\\0{\cdot}31Na^2O\end{array}\right\}0{\cdot}16Al^2O^3,\ 3{\cdot}00SiO^2 + 0{\cdot}46SnO^2.$$

When the surface of the tiles has ornaments in relief, these are simply moulded by hollows in a plaster mould. The manufacture of these wares is relatively easier than that of joined tiles, because any warping in drying and burning is less apparent.

The decoration of these tiles is usually done by means of coloured transparent glazes; the different colours being separated either by a black outline (cloisonné enamels), or by engraving in the moulding deep outlines in the body, which reproduce the design and prevent the enamels from mixing together.

The wares for stoves are made in faience works or in some special factories.

### 3. *So-called Silicious Faiences, with a Fusible Silicious Body.*

**256.** It seems that the first kinds of faience manufactured by the Egyptians, and later by the Persians, were pottery with an extremely silicious body, formed of sand, stuck together by a little alumina and fluxes: alkalies and lime. The glazes are alkaline-plumbous silicates, with brilliant colours. The two frescoes which, thanks to M. Dieulafoy, are now in the Louvre, and which adorned

the palace of the kings of Persia at Susa, are the most beautiful example of ancient Persian art. Similar faience has been found dating from much more recent times. Thus Brongniart gives the following compositions, the first of a paving tile from the Great Mosque at Jerusalem, and the second of a slab from the Tomb of Mahomet at Medina, built in A.D. 707:—

| | | |
|---|---|---|
| Silica | 87·16 | 89·95 |
| Alumina and oxide of iron | 5·50 | 3·87 |
| Lime | 3·00 | 2·00 |
| Magnesia | 0·28 | 0·51 |
| Alkalies | 1·20 | 3·00 |
| Carbonic acid | 2·86 | — |

We have seen, in the history of pottery, that there is no information on the potter's art of the Persians, or of the Arabians, during the first centuries of our era, until the eleventh century, an epoch at which there began, in Spain, the celebrated manufacture of the Hispano-moresque pottery. But these are not of a silicious body; it is an argillaceous calcareous one, and the alkaline enamels gave place to the stanniferous enamels.

It was only towards the year 1850 that the composition of the ancient Persian faiences attracted the attention of potters, and that they attempted to find out the methods that had been employed.

New analyses of the body have given the following composition:—

| | |
|---|---|
| Silica | 90·0 |
| Alumina | 3·0 |
| Alkalies | 6·5 |
| Loss and various substances | 0·5 |
| | 100·0 |

The raw materials made use of are still unknown. The very slight plasticity of this body must have made the moulding very difficult. Some people have suggested as their opinion, that they could not be a manufactured production, but must have been blocks of sandy stone cut out. It does not, however, seem that this explanation is the right one. Perhaps they added to the body some organic materials that gave it a certain softness, and then disappeared when they were burnt.

However that may be, this body was covered in an unburnt state with a first glaze or rather a lustre, composed, according to Lindhorst, of

| | |
|---|---|
| Silica | 90·0 |
| Alumina | 1·0 |
| Oxide of iron | 0·5 |
| Alkalies | 8·0 |
| Waste and various substances | 0·5 |
| | 100·0 |

This lustre was doubtless intended to fill up the pores of the body. Then the whole must have been burnt at a rather high temperature (probably 1,200° C.) at which, by the action of the fluxes, the body would attain a certain hardness. The second glaze had, also according to Lindhorst, the following composition :—

| | |
|---|---|
| Silica | 60 |
| Oxide of lead | 25 |
| Alkalies | 15 |

corresponding to the formula :—

$$\left.\begin{array}{l}0{\cdot}32PbO\\0{\cdot}68Na^2O\end{array}\right\}2{\cdot}82SiO^2,$$

or

$$\left.\begin{array}{l}0{\cdot}39PbO\\0{\cdot}61K^2O\end{array}\right\}3{\cdot}48SiO^2.$$

In 1861 Deck attempted to reproduce these Persian faiences, although with a decidedly different body, but one equally silicious and relatively fusible. He published in his work *La Faience*, the methods he used. We extract the following :—

They begin by making a frit formed of—

| | |
|---|---|
| Fontainebleau sand | 86 |
| Potash | 7 |
| Soda | 3 |
| Chalk | 5 |
| | 100 |

which is powdered dry.

The composition of the body for the ware is :—

| | |
|---|---|
| White earth | 24 |
| Meudon white | 24 |
| Flint | 48 |
| Frit | 4 |
| | 100 |

and that for stove tiles and panels :—

| | |
|---|---|
| White fireclay | 25 |
| Flint | 60 |
| Frit | 15 |
| | 100 |

After being moulded and burnt, the body was covered over with a slip which for the first is composed of

| | |
|---|---|
| Frit | 63 |
| White stanniferous enamel | 32 |
| White earth | 5 |
| | 100 |

It is to be regretted that the exact chemical composition of these mixtures is not known. Besides, Deck made the following remark: "It is not absolutely necessary to add frit to the earth to prevent it cracking; the silica and lime may be sufficient to hinder it, but the frit adds a great deal to the force of the colours; they appear less faded and the whole has a more powerful character. A slightly experienced eye will quickly perceive the superiority of the alkaline body over the non-alkaline." We would observe that, in the bodies for pottery, the proportion of alkalies added by the frit is only 0·4 per cent., and in the body for tiles 1·5 per cent. The former is below the proportion of alkali in pure and in most fireproof clays. Under these conditions it is impossible, even for a potter as clever as Deck, to see any difference at all in the ware, the body of which contains a half or even one and a half per cent. more or less of alkalies.

By reckoning the composition of Fontainebleau sand, of the probable one of the white fireclay, and by leaving out the small amount of oxide of iron, we might give the following composition to the two preceding bodies when burnt:—

| | Body for Pottery. | Body for Tiles. |
|---|---|---|
| Silica | 72 to 74 | 86 to 87 |
| Alumina | 11 ,, 12 | 9·5 ,, 10 |
| Lime | 14 ,, 15 | 1 ,, 2 |
| Alkalies | 1·5 ,, 2 | 2 ,, 2·5 |

As to the slips, they would be composed of

| | Slip for Pottery. | Slip for Tiles. |
|---|---|---|
| Silica | 72·0 to 73·0 | 72·0 to 79·0 |
| Alumina | 1·8 ,, 2·0 | 4·0 ,, 4·2 |
| Oxide of tin | 3·5 | — |
| Oxide of lead | 12·0 | — |
| Lime | 2·0 to 2·2 | 8·8 to 9·0 |
| Potash | 4·6 ,, 4·8 | 6·0 ,, 6·2 |
| Soda | 3·1 ,, 3·2 | 2·7 ,, 2·8 |

They correspond approximately to the formulas

$$\left.\begin{array}{l}0{\cdot}25PbO\\0{\cdot}25CaO\\0{\cdot}25K^2O\\0{\cdot}25Na^2O\end{array}\right\}0{\cdot}10Al^2O^3,\ 6SiO^2 + 0{\cdot}25SnO^2$$

and

$$\left.\begin{array}{l}0{\cdot}60CaO\\0{\cdot}25K^2O\\0{\cdot}15Na^2O\end{array}\right\}0{\cdot}15Al^2O^3,\ 5SiO^2.$$

The total shrinkage of the former body, by drying as well as in burning, would be about 6 per cent., and that of the second only 2 per cent.

The glaze is an alkaline-plumbous silicate, the composition of which is as follows:—

| | |
|---|---|
| Sand | 48 to 50 |
| Red lead | 30 |
| Potash | 12 |
| Soda | 8 to 10 |

The chemical formula is approximately

$$\left.\begin{array}{l}0{\cdot}33PbO\\0{\cdot}33K^2O\\0{\cdot}33Na^2O\end{array}\right\}2SiO^2.$$

The mixture is melted, then powdered dry by preference; the powder does not need to be impalpable. The temperature for burning it varies between 1,000° and 1,200° C.

Lastly, these are the compositions of some of the colours set down by Deck:—

*Flux.*

| | |
|---|---|
| Silica | 70 |
| Red lead | 5 |
| Potash | 15 |
| Soda | 10 |
| | 100 |

*Turquoise Blue.*

| | |
|---|---|
| Flux | 47 |
| Red lead | 6 |
| Oxide of copper | 47 |
| | 100 |

*Dark Blue.*

| | |
|---|---|
| Flux | 50 |
| Red lead | 20 |
| Oxide of cobalt | 30 |
| | 100 |

*Green.*

| | |
|---|---|
| Silica | 30 |
| Alumina | 5 |
| Flux | 10 |
| Red lead | 40 |
| Oxide of antimony | 20 |
| Oxide of copper | 50 |
| Oxide of iron | 10 |
| Chromate of iron | 30 |
| | 195 |

*Light Yellow.*

| | |
|---|---|
| Calcine | 200 |
| Red lead | 65 |
| Antimony | 45 |
| Ammonia | 8 |
| | 318 |

*Dark Yellow.*

| | |
|---|---|
| Silica | 15 |
| Alumina | 5 |
| Calcine | 55 |
| Red lead | 50 |
| Litharge | 45 |
| Oxide of antimony | 73 |
| Oxide of iron | 41 |
| Oxide of zinc | 16 |
| | 300 |

*Rose.*

| | |
|---|---|
| Silica | 20 |
| Carbonate of lime | 35 |
| Stannic acid | 80 |
| Borax | 4 |
| Bichromate of potash | 4 |
| Alumina | 2 |
| | 145 |

*Red.*

| | |
|---|---|
| Red lead | 20 |
| Thiviers stoneware | 80 |

*Red Brown.*

| | |
|---|---|
| Red lead | 20 |
| Calcined Armenian bole | 80 |

*Dark Brown.*

| | |
|---|---|
| Oxide of zinc | 25 |
| Sulphate of iron | 20 |
| Chromate of iron | 40 |
| Oxide of magnesia | 15 |
| | 100 |

*Black.*

| | |
|---|---|
| Silica | 30 |
| Alumina | 6 |
| Red lead | 44 |
| Oxide of antimony | 22 |
| Oxide of iron | 35 |
| Chromate of iron | 20 |
| Oxide of manganese | 40 |
| Oxide of cobalt | 7 |
| Oxide of copper | 15 |
| | 219 |

*White.*

| | |
|---|---|
| Flux | 20 |
| Stanniferous white enamel | 40 |

*White.*

| | |
|---|---|
| Nevers sand | 20 |
| Chalk | 10 |
| Powder porcelain body | 30 |

This mixture is diluted in a silicate of potash at 33° C. The colours having been mixed, on the slab or with a palette knife, with a little gum arabic, are put on with a brush in successive tones for the modelling.

The decoration with coloured glazes is done by making the cells, with a black outline ·04 to ·06 of an inch thick, made of a mixture of the body, some flux and some black colour. As for the transparent enamels, these are some of the compositions :—

*Flux.*

| | |
|---|---|
| Silica | 45 to 50 |
| Red lead | 30 to 35 |
| Potash | 12 |
| Soda | 12 |

*Turquoise Blue.*

| | |
|---|---|
| Flux | 23 |
| Oxide of copper | 7 |

*Blue.*

| | |
|---|---|
| Flux | 25 |
| Silica | 4·3 |
| Oxide of cobalt | 0·7 |

*Green.*

| | |
|---|---|
| Silica | 30 to 35 |
| Borax | 5 |
| Red lead | 55 |
| Potash | 5 to 10 |
| Oxide of copper | 4 |

*Yellow Brown.*

| | |
|---|---|
| Flux | 44 |
| Silica | 20 |
| Red lead | 25 |
| Oxide of iron | 8 |
| Oxide of magnesia | 3 |

*Grenat.*

| | |
|---|---|
| Flux | 82 |
| Soda | 5 |
| Nitrate of soda | 5 |
| Oxide of antimony | 2 |
| Oxide of magnesia | 6 |

*Deep Violet.*

| | |
|---|---|
| Flux | 92·4 |
| Oxide of magnesia | 7·0 |
| Oxide of cobalt | 0·6 |

*Ivory Black.*

| | |
|---|---|
| Flux | 52 |
| Silica | 20 |
| Red lead | 25 |
| Oxide of iron | 3 |

All these enamels are melted and then powdered.

The relatively tender body of the silicious faiences is not resistant enough to be used for domestic purposes, but is admirably suitable for artistic wares, the moulding of which does not need a plastic body, and the decoration of which consists chiefly in the incomparable brightness of the colours.

### 4. *So-called Pipeclay Faiences, with a slightly Fusible Argillaceous Calcareous Body.*

**257.** The so-called pipeclay faiences are characterised by a body that is almost white and hard, formed by the mixture of fireclay that is as little ferruginous as possible, flint, and carbonate of lime. A part of the calcareous flux is sometimes replaced by an alkaline flux.

This body, when slightly burnt, looks like that used for making tobacco pipes, hence its name. But it differs from that by a larger amount of silica, and by being burnt at a higher temperature (1,200° C).

It is the fireclay that serves as a base for the composition of the body. More or less silica is added to it, according to

the degree of plasticity it has, this silica being in the form of sand for ordinary productions, and in the form of calcined flint (Art. 63) for fine goods. Sometimes also a grog of the burnt body is made use of, but only in small proportion. The lime is added to it in the form of marl, the relative plasticity of which is added to that of the clay, and more thinning material is required, either in the form of chalk, which lessens the plasticity, although in a less degree than silica does. The alkaline flux is introduced in the form of feldspar; it is usually as thinning a material as flint.

We can, in a very general way, characterise the composition of the body by the following mixture in theory :—

| | |
|---|---|
| Pure clay | 30 |
| Silica | 50 |
| Carbonate of lime | 20 |
| | 100 |

which gives when burnt a body formed of

| | |
|---|---|
| Silica | 72·6 |
| Alumina | 15·2 |
| Lime | 12·2 |

The following, by way of example, are the different ways of obtaining bodies of this class :—

| | | | |
|---|---|---|---|
| Plastic fireclay | 40 | 40 | 40 |
| Flint | 40 | 35 | 35 |
| Cement | — | 5 | 5 |
| Chalk | 20 | 20 | 16 |
| Feldspar | — | — | 4 |
| | 100 | 100 | 100 |

| | | |
|---|---|---|
| Thin fireclay | 60 | 60 |
| Flint | 20 | 20 |
| Chalk | 20 | 16 |
| Feldspar | — | 4 |
| | 100 | 100 |

| | |
|---|---|
| Plastic fireclay | 25 |
| Flint | 42 |
| Cement | 5 |
| Plastic marl | 28 |
| | 100 |

Sometimes a certain proportion of kaolin is added to the body, which, as it contains less iron than clay does, has the

effect of whitening the mass. In that case we must naturally take account of the fluxes that it may contain. Here is the composition of a somewhat complex body which carries out this idea :—

| | |
|---|---|
| Plastic fireclay | 15 |
| Thin fireclay | 45 |
| Alkaline kaolin | 5 |
| Flint | 20 |
| Chalk | 10 |
| Feldspar | 5 |
| | 100 |

The glazes formerly used were very tender alkaline plumbiferous silicates, as the following composition shows, as set down by Bastenaire :—

| | |
|---|---|
| Quartzeous sand | 36 |
| Red lead | 45 |
| Carbonate of soda in solution at 80° C. | 17 |
| Nitrate of potash | 2 |

or it may be approximately :—

| | |
|---|---|
| Silica | 40·4 |
| Oxide of lead | 49·0 |
| Soda | 9·6 |
| Potash | 1·0 |
| | 100·0 |

corresponding to the formula

$$\left.\begin{array}{l} 0{\cdot}57PbO \\ 0{\cdot}03K^2O \\ 0{\cdot}40Na^2O \end{array}\right\} 1{\cdot}75SiO^2.$$

Since then, in preference, the alkaline plumbiferous boracic glazes have been employed, especially for pottery before it is decorated.

The following, by way of examples, are five compositions for glazes of this kind given by Prössel :—

*Frit.*

| | | | | | |
|---|---|---|---|---|---|
| Feldspar | 41·5 | 35 | 16 | 30 | 24 |
| Sand | 13·3 | 18 | 29 | 22 | 30 |
| Red Lead | 18·5 | 16 | — | — | — |
| Borax | 16·5 | 22 | 29 | 30 | 35 |
| Kaolin | 2·7 | 3 | 10 | 3·5 | 6 |
| Potash | 1·0 | — | — | 4·5 | 3 |
| Chalk | 6·5 | 6 | 15 | 11 | 12 |

*Glaze.*

| | | | | | |
|---|---|---|---|---|---|
| Frit | 90 | 82 | 58 | 65 | 65 |
| White lead | 9 | 8 | 26 | 24 | 13 |
| Sand | — | — | — | — | 11 |
| Feldspar | — | 10 | 16 | 11 | 11 |

The frit having been prepared, it is mixed, in the proportions indicated above, with the white lead, sand or feldspar, and the whole powdered. By using Norwegian feldspar, these glazes have approximately the following compositions :—

| | | | | | |
|---|---|---|---|---|---|
| Silica | 43·4 | 47·8 | 44·8 | 42·9 | 53·1 |
| Boracic acid | 6·0 | 7·2 | 7·1 | 8·1 | 9·6 |
| Alumina | 9·2 | 9·4 | 8·8 | 8·0 | 7·4 |
| Oxide of lead | 27·6 | 22·6 | 26·2 | 23·6 | 13·1 |
| Lime | 3·9 | 3·3 | 6·1 | 5·0 | 5·5 |
| Potash | 7·4 | 6·6 | 4·0 | 9·0 | 7·2 |
| Soda | 2·5 | 3·1 | 3·0 | 3·4 | 4·1 |

Lastly, they can be represented by the formulas

$$\left.\begin{array}{l}0{\cdot}39PbO\\0{\cdot}21CaO\\0{\cdot}27K^2O\\0{\cdot}13Na^2O\end{array}\right\}0{\cdot}28Al^2O^3\left\{\begin{array}{l}2{\cdot}26SiO^2\\0{\cdot}26BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}35PbO\\0{\cdot}21CaO\\0{\cdot}27K^2O\\0{\cdot}17Na^2O\end{array}\right\}0{\cdot}32Al^2O^3\left\{\begin{array}{l}2{\cdot}77SiO^2\\0{\cdot}36BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}37PbO\\0{\cdot}34CaO\\0{\cdot}14K^2O\\0{\cdot}15Na^2O\end{array}\right\}0{\cdot}30Al^2O^3\left\{\begin{array}{l}2{\cdot}33SiO^2\\0{\cdot}35BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}30PbO\\0{\cdot}25CaO\\0{\cdot}29K^2O\\0{\cdot}16Na^2O\end{array}\right\}0{\cdot}22Al^2O^3\left\{\begin{array}{l}2{\cdot}01SiO^2\\0{\cdot}40BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}19PbO\\0{\cdot}32CaO\\0{\cdot}28K^2O\\0{\cdot}21Na^2O\end{array}\right\}0{\cdot}20Al_2O^3\left\{\begin{array}{l}2{\cdot}88SiO^2\\0{\cdot}45BO^3\end{array}\right.$$

For the purpose of hiding the slightly yellowish tinge of the body, from a half to one thousandth part of oxide of cobalt is added to the glaze.

The pipeclay has been manufactured especially in the north-east of France and the west of Germany. We have just seen that the composition of the body, which was originally purely argillaceous-calcareous, has been modified little by little by the introduction of feldspar and kaolin. In the same way the

alkaline-plumbiferous glaze has become boracic and alkaline-earthy. They have gradually become in some degree similar to the feldspathic faiences, which, at the present time, are more generally used. Nevertheless for cheap ware pipeclay can still be of service. As to the methods of manufacture, they are the same as those employed for feldspathic faiences, which will be discussed further on.

### 5. *Faiences called Pebble Work, with a Fireproof Argillaceous Silicious Body.*

**258.** The body for the kind of faience called pebble work is almost white, hard and fireproof. It is formed by the addition of a certain proportion of flint to a white fireclay that is as little ferruginous as possible. The flint is obtained by burning and powdering pebble (page 73), whence its name of pebble work. The proportion of flint mixed with it depends naturally on the plasticity of the clay; it varies from 10 per cent. to 30 per cent.

At the present time, in order to give a whiteness to the body, it is preferable to replace a part of the clay and flint by a silicious kaolin. The composition of these mixtures is too variable to be able to give in this connection even approximate tables.

The glaze is plumbiferous, alkaline or alkaline-earthy and boracic, of a composition similar to that for pipeclays. Harder glazes can also be made use of, like those employed for feldspathic faiences, of which we shall speak in the following article.

Among the faiences of this kind are classed certain English wares, with a body coloured red by oxide of iron, obtained by Wedgwood; this is done by using a ferruginous clay in the composition of the body.

Pebble work, which was very much in fashion at the end of the eighteenth century, is very little used at the present time. The body should be burnt at a high temperature, in consequence of the absence of flux, and it never acquires the hardness and shine of the feldspathic faiences, nor even of the pipeclay ones.

### 6. *So-called Feldspathic Faiences, with a slightly Fusible Argillaceous Alkaline Body.*

**259. Composition.**—The faiences called feldspathic have a white, or sometimes slightly yellowish, hard body, which, in some varieties, becomes very slightly translucent, thus approaching porcelain. At the present time it is formed by the mixture of plastic clay, kaolin, flint and feldspar, or pegmatite. The parts played by these different substances are the following: The plastic fireproof clay, which is white and as little ferruginous as possible, naturally serves as a basis. To it is added some kaolin, to whiten the body, because even the purest clays always have a yellowish tinge at a high temperature. The flint helps to open it and at the same time gives it whiteness and hardness. It can be replaced by pure sand, but only if that is first heated to make its density 2·2 to 2·3 and prevent its swelling afterwards, which would involve the splitting of the body while it was being burnt. Lastly, the feldspar or pegmatite serves as a thinning material and especially as a flux.

The proportions in which these four substances can be mixed are variable; they depend not only on the variable compositions of the raw materials, but also on the quality of the body that is desired and on economical considerations.

The English method of manufacturing it has served as a type of all the others, and the raw materials employed in England are still very often utilised, in whole or in part, in other countries. These materials are: Blue clay from Wareham and Corfe Castle (Dorsetshire), kaolin (China clay) from Cornwall, flint from the pebbles of the Thames and the Somme, and pegmatite (Cornish stone) from Cornwall. The following are some examples of the composition of the English bodies obtained with these materials:—

| | | | | | | |
|---|---|---|---|---|---|---|
| Blue clay . . . . . | 47 | 43 | 31 | 24 | 21 | 18 |
| Kaolin . . . . . | 24 | 24 | 36 | 27 | 28 | 43 |
| Flint . . . . . | 22 | 23 | 21 | 36 | 38 | 24 |
| Pegmatite . . . . . | 7 | 10 | 12 | 13 | 13 | 15 |

In a general way there is a tendency to increase the proportion of kaolin to make the body whiter, and that of the

pegmatite to increase its fusibility, and consequently its hardness.

It must be remarked that besides the modifications that may be made in the qualities of the bodies by varying the proportion of the four constituent elements, it can also be done by altering the temperature at which it is burnt. A more intense heat allows of less flux being used. In order to judge *a priori* of the quality of the body, we must not only know the composition of it, but also the temperature at which it was burnt.

In the faience potteries which have been established in the different countries they have tried to replace the English raw materials by those of their own countries. Thus, they have used in France the clays of the lower tertiary strata (Cessey in Seine-et-Marne, Monpothier in l'Aube, etc.), the kaolins of l'Allier, the flint from Dieppe, the feldspars or pegmatite from Haute-Vienne. In some cases an alkaline silicious kaolin may may in a more or less degree replace the flint and pegmatite.

The following, according to Seger, are the compositions of five bodies for feldspathic faiences: (*a*) a body composed of clay of French extraction and feldspathic kaolin from Saint-Yrieix; (*b*) a body formed of French clay and kaolin, quartzeous sand and Norwegian feldspar; (*c*) and (*d*) bodies made with Belgian clay, kaolin and pegmatite from Cornwall and flint from Dieppe, the first for fine ware, the second for common ware; lastly (*e*) is a body of German origin.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| Silica | 61·71 | 67·45 | 65·92 | 61·70 | 64·25 |
| Alumina | 26·69 | 21·59 | 23·62 | 27·01 | 21·46 |
| Oxide of iron | 1·14 | 0·59 | 0·59 | 0·61 | 0·54 |
| Lime | tr. | — | tr. | 0·65 | 2·38 |
| Magnesia | 0·06 | 0·51 | 0·22 | 0·25 | tr. |
| Potash | 1·30 | 1·92 | 1·48 | 1·32 | 1·97 |
| Soda | — | 0·24 | 0·60 | 0·67 | 1·03 |
| Carbonic acid | — | — | — | — | 1·99 |
| Water and organic substances | 9·24 | 7·23 | 7·24 | 8·11 | 6·12 |
| | 100·14 | 99·53 | 99·37 | 100·32 | 99·74 |

The glazes have a similar composition to those for pipeclay, but usually they are a little harder, that is to say, they contain more silica and alumina. This hardness is, however, compen-

sated for partly by a larger proportion of boracic acid. The following, according to Prössel, are the compositions of several of these glazes:—

*Frit.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pegmatite | — | — | 31 | 25 | — | 41 | — |
| Sand | 35 | 28 | 17 | 10 | 26 | 24 | 32 |
| Borax | 35 | — | 30 | — | — | 32 | — |
| Boracic acid | — | 17 | — | 18·5 | 15 | — | 18 |
| Red lead | — | — | — | — | 19 | | |
| Soda crystals | — | 22 | — | 23·5 | 16 | — | 20 |
| Kaolin | 12 | 15 | 11 | 8 | 11 | 3 | 13 |
| Chalk | 18 | 17 | 11 | 15 | 13 | — | 16 |

*Glaze.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Frit | 52 | 47 | 74 | 60 | 70 | 59 | 60 |
| White lead | 18 | 21 | 12 | 18 | 6 | 18·5 | 22 |
| Pegmatite | 30 | 31 | 8 | 22 | — | 11 | 18 |
| Feldspar | — | — | — | — | 23 | — | — |
| Flint | — | — | 6 | — | — | — | — |
| Chalk | — | — | — | — | — | 11·5 | — |

The composition of these vitrified glazes is approximately the following:—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Silica | 53·4 | 49·3 | 56·7 | 45·4 | 46·0 | 50·6 | 46·3 |
| Boracic acid | 7·8 | 8·3 | 8·8 | 11·8 | 4·6 | 8·1 | 11·4 |
| Alumina | 9·1 | 10·7 | 11·4 | 10·9 | 14·6 | 8·3 | 8·3 |
| Oxide of lead | 17·9 | 21·1 | 11·2 | 18·9 | 21·4 | 19·0 | 22·8 |
| Lime | 6·2 | 5·5 | 5·3 | 6·4 | 6·2 | 8·0 | 6·8 |
| Potash | 2·2 | 2·4 | 2·8 | 2·9 | 4·4 | 2·6 | 1·5 |
| Soda | 3·4 | 2·7 | 3·8 | 3·7 | 2·8 | 3·4 | 2·9 |

Their chemical formulas may be represented as follows:—

$$\left.\begin{array}{l}0{\cdot}30PbO\\0{\cdot}40CaO\\0{\cdot}10K^2O\\0{\cdot}20Na^2O\end{array}\right\}0{\cdot}33Al^2O^3\left\{\begin{array}{l}3{\cdot}11SiO^2\\0{\cdot}65BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}36PbO\\0{\cdot}38CaO\\0{\cdot}11K^2O\\0{\cdot}15Na^2O\end{array}\right\}0{\cdot}40Al^2O^3\left\{\begin{array}{l}3{\cdot}10SiO^2\\0{\cdot}77BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}21PbO\\0{\cdot}40CaO\\0{\cdot}11K^2O\\0{\cdot}25Na^2O\end{array}\right\}0{\cdot}45Al^2O^3\left\{\begin{array}{l}3{\cdot}93SiO^2\\0{\cdot}62BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}29PbO\\0{\cdot}39CaO\\0{\cdot}12K^2O\\0{\cdot}20Na^2O\end{array}\right\}0{\cdot}35Al^2O^3\left\{\begin{array}{l}2{\cdot}56SiO^2\\0{\cdot}76BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}32PbO\\0{\cdot}37CaO\\0{\cdot}17K^2O\\0{\cdot}14Na^2O\end{array}\right\}0{\cdot}47Al^2O^3\left\{\begin{array}{l}2{\cdot}59SiO^2\\0{\cdot}22BO^3\end{array}\right.$$

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$$\left.\begin{array}{l}0{\cdot}27PbO\\0{\cdot}47CaO\\0{\cdot}08K^2O\\0{\cdot}18Na^2O\end{array}\right\}0{\cdot}36Al^2O^3\left\{\begin{array}{l}2{\cdot}73SiO^2\\0{\cdot}37BO^3\end{array}\right.$$

$$\left.\begin{array}{l}0{\cdot}36PbO\\0{\cdot}42CaO\\0{\cdot}06K^2O\\0{\cdot}16Na^2O\end{array}\right\}0{\cdot}29Al^2O^3\left\{\begin{array}{l}2{\cdot}75SiO^2\\0{\cdot}59BO^3\end{array}\right.$$

The composition of the bodies and the glazes for feldspathic faiences having thus been settled, we will now examine the processes of making them, these being the same for pipeclay and pebble work ones.

**260. Preparation of the Bodies.**—The raw materials which enter into the preparation of the bodies ought first to be purified or disaggregated.

The *clays* are employed in faience works either in a natural state or else purified by being washed; this washing can be done in the pits or in the factory. It is necessary, as a general rule, to wash them, employing the methods described in Art. 75.

The *kaolins* are always washed, this operation usually taking place in the pits by the same methods.

The *flint* ought first to be heated and powdered, operations that can be done either in the faience works or else in special works (see Art. 63).

Lastly, the *feldspar* or pegmatite is broken up or powdered, chiefly in the faience works, sometimes also near the quarries. The different methods of grinding them have been described in Chapter III.

The result is that in the preparation of the body, which is always done in a liquid state, it is necessary:—

1. To dissolve the clay in water, at least when the washing of it is not done in the faience works, so that the liquid body can be directly made use of.

2. To dissolve the kaolin.

3. To reduce the flint to an impalpable powder and dilute it.

4. To do the same with the feldspar.

The methods used for this purpose have been described in Chapter III. (Art. 92). It is sufficient to add that these four operations are usually done in diluting machines, mills with blocks

or separate Asling cylinders, specially used for each substance. (When there is any limestone in the composition of the body it is generally powdered and diluted at the same time as the flint.) The method is to put into each machine as nearly as possible a definite proportion by volume of the solid material and water, then, when the substance is entirely pulverised and completely diluted, the mixture is allowed to run out into four reservoirs. There it is noticed whether the consistency of the different liquids is the same as that shown as a type. We have seen that for this purpose the weight of a certain specified volume is taken, a pint or half pint of the liquid, for example; direct experiments, on the other hand, having decided the proportion of solid matter which corresponds to the different densities. The diluting is nearly always done with a slight excess of water, so that while drawing off the liquid the proper consistency can be obtained. It is seldom that a thicker body, which is contained in a special reservoir, has to be used to correct it.

We have seen that, in order for the mixing to be well done, it is necessary that the four liquids should be of about the same consistency, but then they are not of the same density. Here, by way of example, are the figures of an ancient English formula :—

| | Ounces per Pint. | Grammes per Litre. |
|---|---|---|
| Plastic clay (blue clay) . . . | 24 | 1,200 |
| Kaolin (China clay) . . . . | 26 | 1,300 |
| Silica (flint) . . . . . | 32 | 1,600 |
| Pegmatite (Cornish stone) . . . | 32 | 1,600 |

The four liquids being thus of the required consistency, they are allowed to run into a single reservoir, in succession, there being a graduated vertical scale for introducing the definite quantities, measured by the level reached by the liquid on this gradation. Thus, by following out the preceding example, it would need

| | Centimetres. |
|---|---|
| Plastic clay . . . . . | 46 |
| Kaolin . . . . . | 22 |
| Flint . . . . . | 16 |
| Pegmatite . . . . . | 16 |

The continuation of the preparation of the body is then carried on as we have said, by mixing up the liquid, by sifting it, once,

twice or even three times, through finer and finer sieves, running it off and making the body firmer by filter-presses. The cakes of body thus obtained are put in cellars, and then kneaded before being used in moulding.

**261. Moulding.**—The body which is fairly plastic for feldspathic faience is usually suitable for all the methods of moulding as they were described in Chapter IV. Specially, moulding by

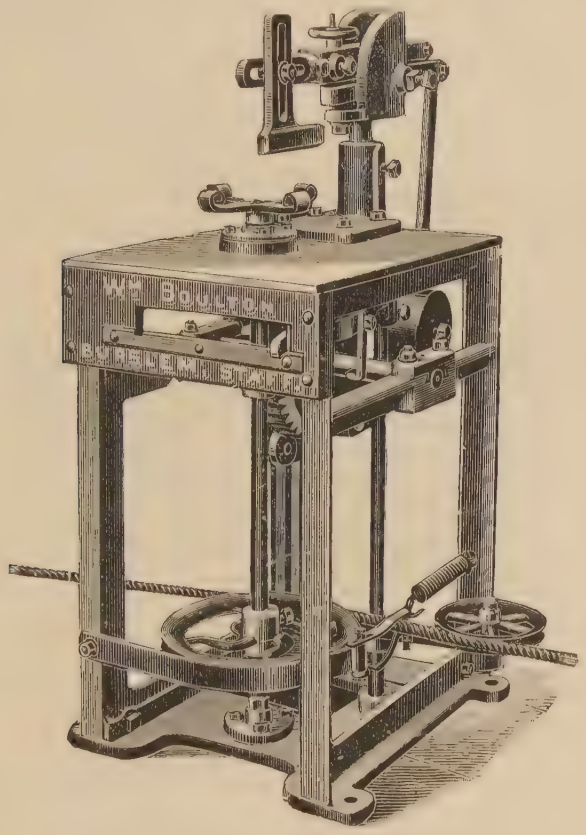



Fig. 282.—A Lathe for Making batts.

hand in plaster moulds is used for all pieces that cannot be turned; moulding on the wheel is generally used for making all round objects for domestic purposes; lastly, moulding in a press is employed for making paving tiles. As these last two methods are of special importance in faience potteries, it would be wise to enter into more details on the subject of them.

In moulding on a dish, flat or shaped pieces are distinguished (plates, saucers, bowls, etc., in a word flat ware) from the higher

goods or those contracted at the upper part, that is to say, hollow ware. Flat ware is made by two operations: throwing for making the batts for it, and an after moulding on the jigger.

For large objects and more careful ones, the throwing is done on the head of the wheel, the principle of which was shown in Fig. 96 (page 217). The templet may be worked by hand or automatically, as shown in Fig. 282, that represents a machine of this kind made by Mr. Boulton. The machine having been

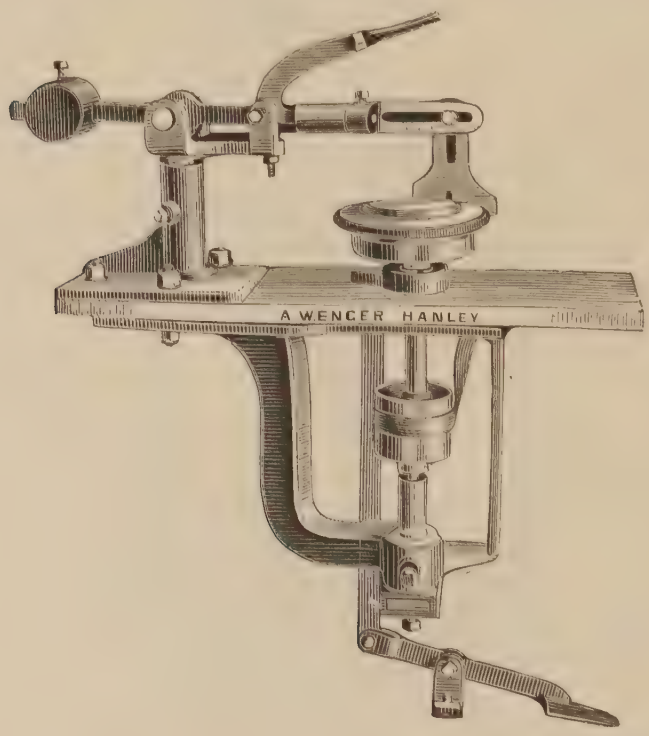



Fig. 283.—Wheel for Moulding Flat Ware.

stopped, they place, on a slab over the wheel head, a ball of clay, then start the machine. The templet descends, makes the shape, then rises again and the machine unloads itself automatically.

The slab is then placed on a plaster mould having the profile of the interior of the ware (Fig. 98), and a templet is lowered by hand, which shapes the body and gives it the outside form. Fig. 283 shows a machine of this kind made by Mr. Wenger. In some cases the two preceding machines are placed side by

side, in such a way as to be able to be worked by one moulder. An arrangement of this description, shown in Fig. 284, and made by Mr. Boulton, allows of 500 pieces an hour being manufactured.

Lastly, the slabs can also be made on leather discs, stretched over a ring that is placed on the bed-plate of the machine (Fig. 284). These discs are afterwards carried away with the shape and turned over on to the mould. In this case the machine shown in Fig. 285 is used, in which there are four

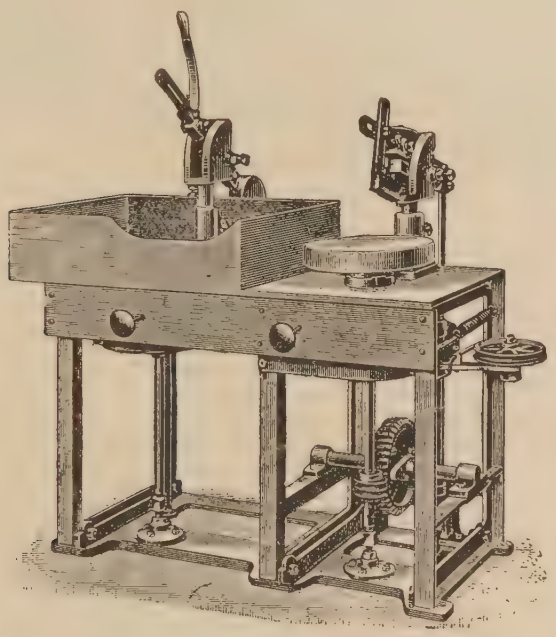


Fig. 284.—Wheel for Making the Shapes and for Moulding them.

moulds placed on a carriage. Two of these moulds are centred on the bed-plates of two twin wheels, the templets for which are moved automatically, while a workman takes away the manufactured objects from the other two and replaces them by slabs. When the moulding is finished, the moulder pushes the carriage towards the left, a movement which allows of the finished pieces being taken away and new slabs being placed, while the fashioning of the two new slabs goes on. A machine of this kind allows of the fashioning of 5 to 600 pieces an hour.

For making hollow goods, when the objects are not too large, belt making can be left out. Then the arrangement described

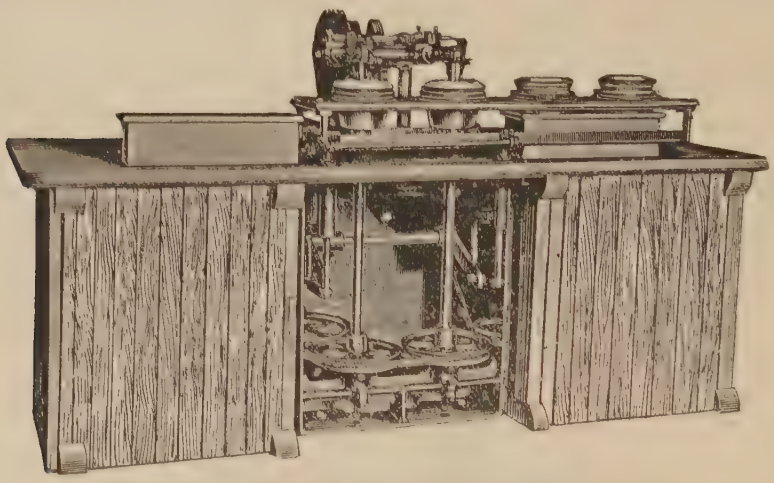


Fig. 285.—Double Wheel, for Moulding Flat Articles.

on page 219 (Fig. 100) is made use of. Fig. 286 represents an automatic machine of this kind made by Mr. Boulton, in

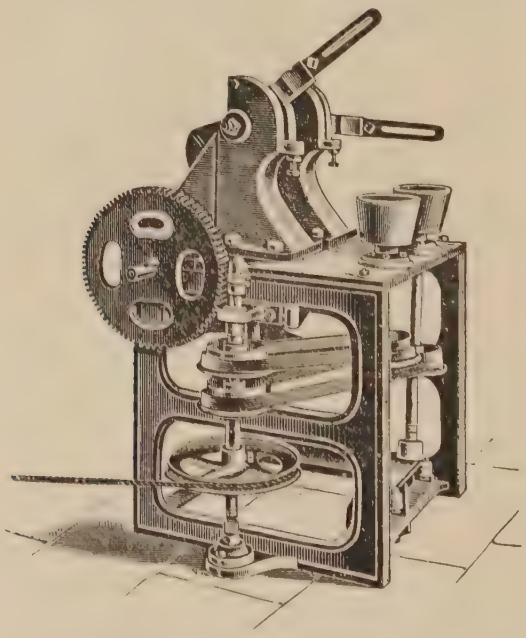


Fig. 286.—Jolley for Moulding Cups, Bowls, etc.

which 500 objects an hour can be turned out. The motion is continuous. As soon as one object is made and the templet

raised, the mould is replaced by another containing some body. For wares of large size it is necessary to throw it first or make a shape of them. The see-saw motion of the templets, which is the usual one, is, in large ware, replaced by an up and down motion, the templet being fixed to a transverse beam, as shown in Fig. 95 (page 216). Fig. 287 shows a machine of the same

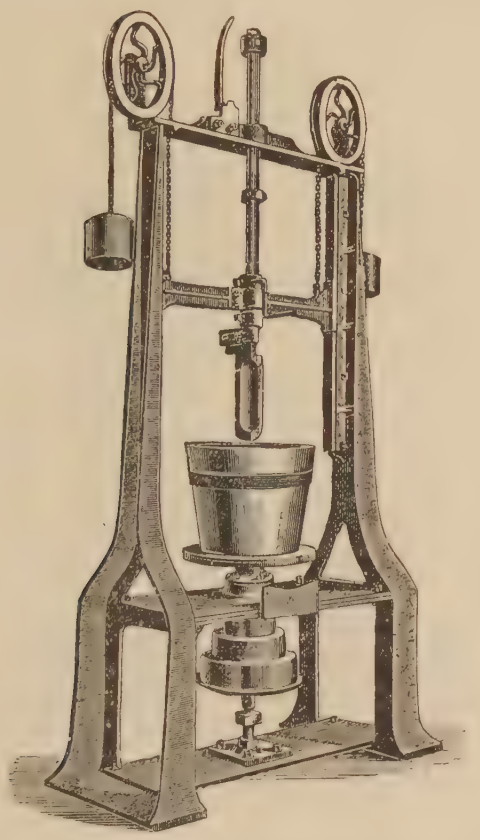


Fig. 287.—Jolley for Moulding Large Hollow Pieces.

kind for very large objects. If the latter have a narrow neck, then the arrangement described on page 219 (Fig. 100) is used.

Paving tiles are very often manufactured in a press of firm or even dry body. In that case the preparation is done as has already been described; then, when it comes out of the filter press, the cake of body is dried either in the open air, or on heated surfaces, or else in hot air drying places.

The dry body is then broken up coarsely by hand, and put into

a kneading machine, adding to it, when necessary, the quantity of water needed to make it suitably moist. When it comes out of the kneading machine it falls into a pulveriser by centrifugal force, which reduces it to a powder. These two operations may be done simultaneously in the machine shown in Fig. 288, which, according to the pattern, can produce from 6 cwt. to 2 tons an hour, at an expenditure of 4 to 5 horse-power.

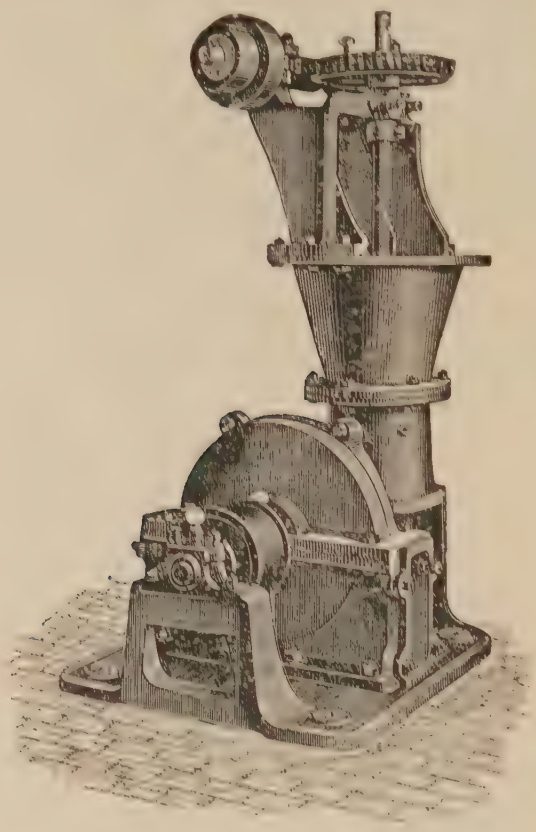


Fig. 288.—A Pulverising Machine.

The powder is afterwards put into a metallic mould and pressed by means of a machine with a fly wheel. Fig. 289 shows a press of this description, made by Mr. Boulton, in which the emptying the mould is done by means of the lower part of the mould being raised with the help of a lever or a pedal. These presses are made in several patterns, according to the dimensions of the paving tiles. The following are some of the results of their production.

| | | | Production per hour, |
|---|---|---|---|
| Press moulding | one paving tile | 1·97 in. | 250 to 320 |
| ,, | two paving tiles | 1·97 ,, | 300 ,, 400 |
| ,, | one paving tile | 3·93 ,, | 150 ,, 200 |
| ,, | two paving tiles | 3·93 ,, | 250 ,, 300 |
| ,, | one paving tile | 5·90 ,, | 120 ,, 140 |
| ,, | ,, | 7·87 ,, | 100 ,, 120 |
| ,, | ,, | 11·81 ,, | 40 ,, 60 |

For large quantities friction presses worked by an engine must be made use of, of the kinds that were mentioned when speaking of making tiles (page 227, Fig. 107, and page 522, Fig. 257).

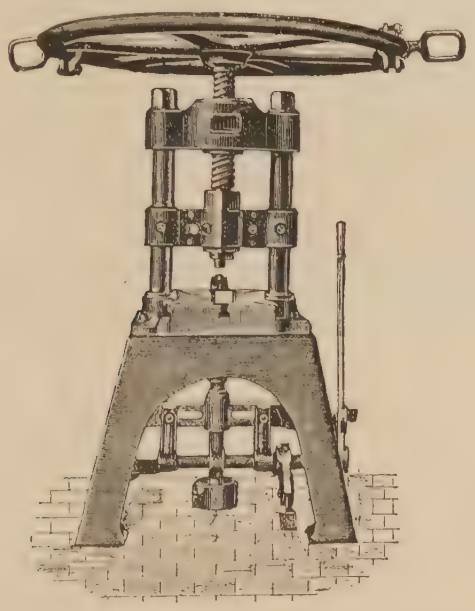


FIG. 289.—Press for Moulding Paving Tiles.

The manufacture on a turning lathe, as also that by casting, which are sometimes employed in faience potteries, will be mentioned in the chapter devoted to the manufacture of porcelain, in which they are much more used.

**262. Drying.**—When the goods have been made in plaster moulds, they are left to dry in these moulds until they can be raised, so as to pile them up and put them to dry. The moulds containing the moulded body are placed on stages arranged in the moulding shops. In some cases drying sheds heated by hot air, or by means of steam pipes, are made use of. In Chapter V.,

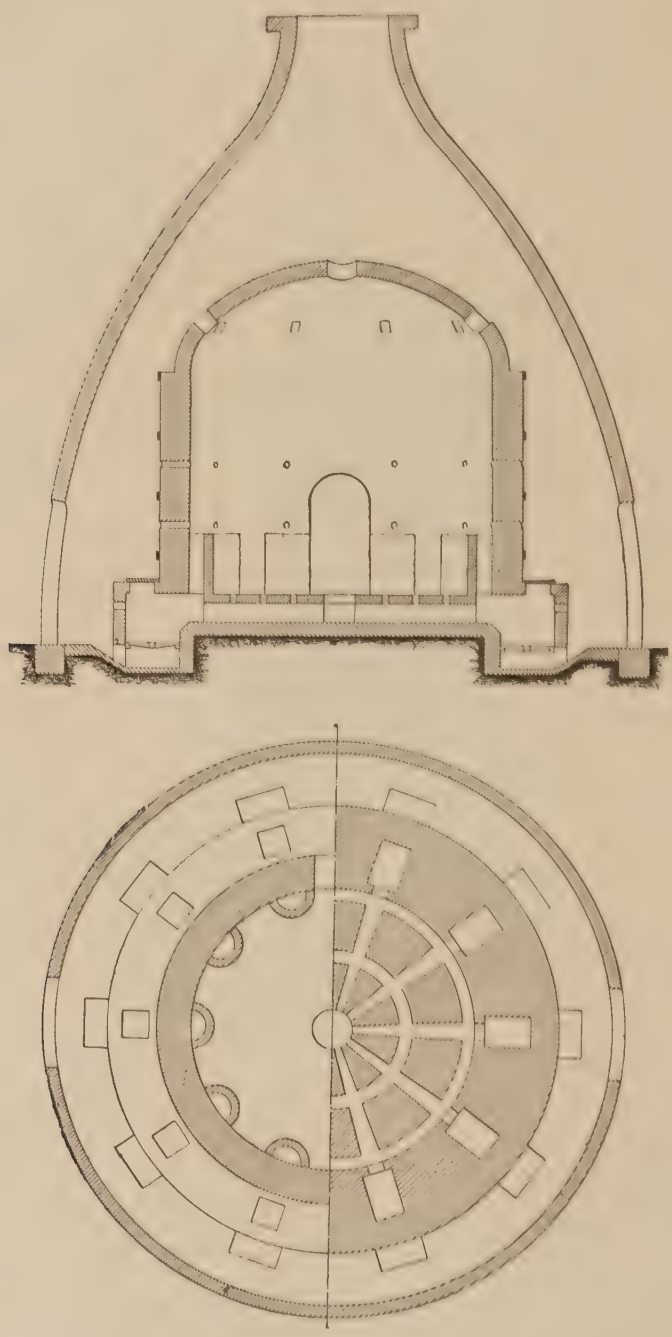
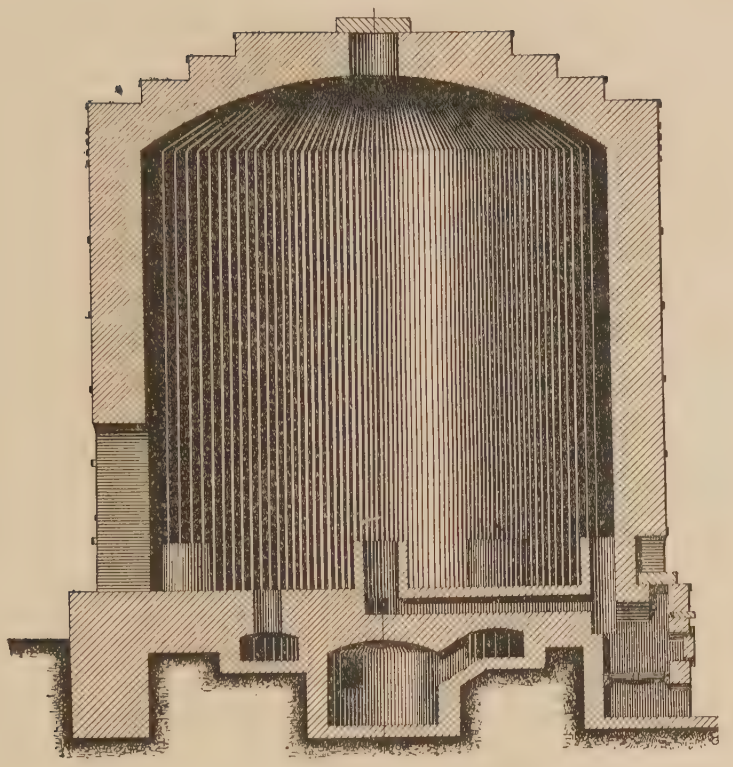


Fig. 290.—A Kiln for Earthenware.



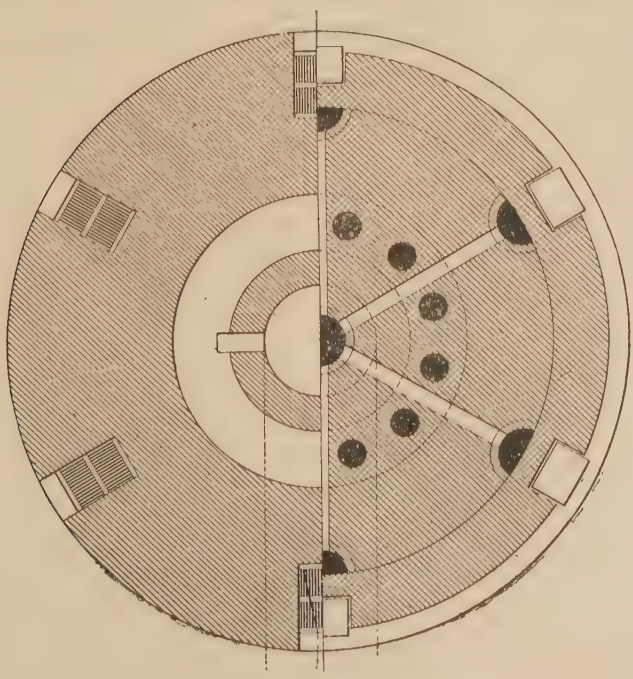


FIG. 291.—A Kiln for Earthenware.

pages 261, 262 (Figs. 123 and 124), were described the arrangements of revolving dryers which are generally used in that case.

Artificial drying is indispensable in the moulding shops where wheels worked by machine are employed. Their large output would involve a vast increase of drying places in the open air, which would be incompatible with the economical use of the motive power and of hand work. On the other hand, as during bad weather the drying can only be done by means of a fairly intense heat, and as in places where people are a sufficiently active ventilation cannot be obtained, the result is that the atmosphere of the workrooms would be charged with steam, and would act in an injurious manner on the health of the workpeople.

Lastly, the drying of the plaster moulds is only very slow in the open air, and it is better, in order to increase the production, to hasten the drying of them by an artificial process.

**263. Burning.**—For a long time for burning earthenware round kilns with ascending flames were used, surrounded by a cupola (hovel) ending in a chimney (Fig. 290). The cupola was for the double purpose of ensuring a draught and of isolating the kiln from the workrooms, or, when placed outside the buildings, to protect it from the weather. This arrangement is still very much used, especially in England.

At the present time they prefer round kilns with descending flames, the draught being caused by means of a chimney apart, which may be a common one for several kilns. Fig. 291 represents a kiln of this kind. The furnaces, to the number of from six to ten, communicate with a central opening for the fire. The gases are carried off by a series of openings arranged concentrically in the lower hearth, which communicate with a circular receiver, that is itself united by several channels with a central passage for the smoke, into which opens the channel leading to the chimney. The diameter of these kilns varies from $11\frac{1}{2}$ ft. to $19\frac{2}{3}$ ft., and the height from $13\frac{1}{4}$ ft. to 23 ft. The medium size ones are these that give the best results. The slow firing usually lasts from six to eight hours, and the hard firing from sixteen to twenty-four hours. The consumption of fuel, which varies a good deal in the different potteries, may

be reckoned at from 5·62 lb. to 6·25 lb. per cubic foot of the capacity of the kiln. It is very advisable to lose as little space as possible in charging, because the quantity of fuel consumed remains of course the same, whatever may be the weight of the goods put in.

By way of very general directions, we may represent as follows the thermic balance-sheet of a kiln of this description :—

| | | | |
|---|---|---|---|
| Heat produced by combustion . | 100 | Heat theoretically necessary . . | 17 |
| | | Heat lost in charging . . . | 34 |
| | | Heat lost by the heating of the walls . . . . . | 10 |
| | | Heat lost through the chimney . | 25 |
| | | Heat lost by an incomplete combustion . . . . . | 4 |
| | 100 | | 100 |

For burning faience the kilns with continuous firing have also been employed, heated by gas, with several burning spaces. We cannot say that the results obtained up to the present time are very satisfactory. Yet we believe that this question will be solved at some future time, either sooner or later. We should not, however, exaggerate, as has been done sometimes, the importance of the economy in fuel which has been attained by this means. In regard to the foregoing balance-sheet one could collect again about 30 per cent. of the heat produced by combustion, and, on the other side, could reduce to 5 per cent. or 10 per cent. the loss through the chimney; but, on the other hand, the losses due to heating the walls and by radiation would be increased, and it would be necessary to add to them the loss due to generating the gas. We think, then, that an economy of fuel of 20 per cent., or, at most, of 30 per cent., would be all that could be attained. It is true that the workman's labour of charging would also be noticeably reduced. We shall find in the following chapter (page 677) other directions as to this kind of kiln with continuous firing.

We know that faience needs two heatings, the first at a temperature of about 1,200° C. for burning the body, and the second between 1,000° and 1,100° C. for vitrifying the glaze. These two heatings are usually done in succession in the same kilns, the

latter using only 5·00 lb. to 6·25 lb. per cubic foot of the charge; but, as we shall see in the following article, the quantity of ware that it is possible to charge at one time being smaller, the expenditure of fuel is really the same, or even rather greater for burning the glaze.

**264. Setting and Placing in Saggers.**—The charging is always done in saggers, these being piled on one another, leaving a certain space between the last sagger and the dome. These piles of saggers are arranged concentrically, the outer row being placed at a certain distance from the wall (3 to 6 inches).

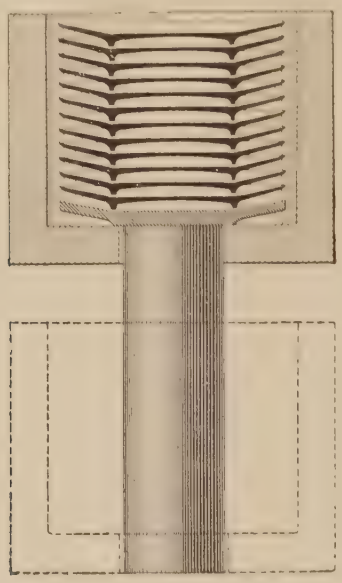


Fig. 292.—Methods of Filling the Saggers.

The piles which compose it are put against one another in such a manner as to guide the flames towards the dome. The inside piles are also close together, but to allow of the circulation of the gases on the hearth, the first sagger at the bottom is placed on a pedestal formed of firebricks.

As saggers of different sizes have to be used, they try, by arranging the smaller ones in the places left between the larger ones, to fill the kiln as full as possible. This method of charging is the one suitable for kilns with descending flames; for those with ascending flames it is necessary to separate the piles, supporting them against each other by means of little

pieces of fireclay put against the saggers. The filling of the saggers with dry bodies does not, as a general rule, offer any difficulty, because, in the interior of the same sagger, they can be piled up, that is to say, they can be put into the sagger in a heap. All the art consists in placing the greatest possible number of objects. For pieces like plates, which have a diameter nearly equal to that of the sagger, which does not allow them to be put into the sagger by hand, the method shown in Fig. 292 is employed: on a round block of wood, placed on a table in the middle of a sagger, is arranged a piece of fireclay, on which are piled up ten to twelve plates, then by raising the sagger, the operation of filling the sagger is completed. It is sufficient not to load the lower pieces too much, which might cause them to break.

The filling of the saggers for burning the glaze is much

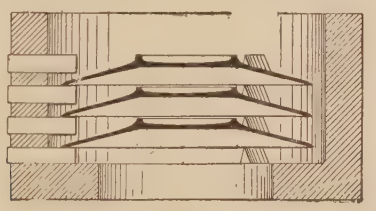


Fig. 293.—Method of Filling the Sagger.

more difficult, because in that case, the glaze prevents the piling up of the ware. Different methods are resorted to, which consist, in theory, of placing the ware, when made very solid by a previous burning, on small fireclay supports, leaving only a point or a small part in contact with the piece.

The following are some examples of the most usual arrangements:—

Fig. 293 shows a section of a sagger, into the walls of which are embedded small triangular pieces called *head-pins*, which serve to support the pieces. For this purpose the saggers are pierced with triangular holes, which, when the head-pins are put in, are filled up by means of a little fireclay. Contrary to what is shown in the drawing, these head-pins are not placed along a vertical line, but following the line of a helix, so as not to weaken the sagger too much.

Instead of piercing holes in the saggers, *supports called bowl pins* can be placed along the walls, as shown in Fig. 294, which are approximately of the shape of truncated or triangular pyramids, and which are piled up on one another.

Following out the same idea, *thimbles* can be used, that is to say, small hollow truncated cone-shaped pieces, fitting into

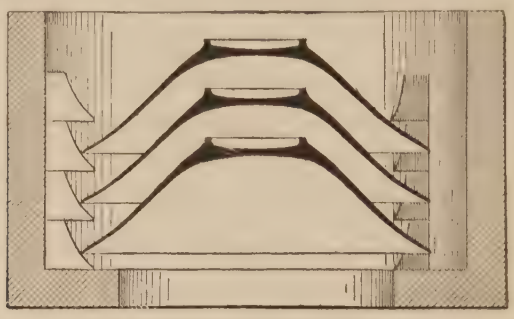


FIG. 294.—Method of Filling the Sagger.

one another and having a small triangular projection, on which are placed the plates or tiles, as shown in Fig. 295. In order to keep this scaffolding up, at the lower part is put a ring bearing three thimbles fastened to it, and at the upper part a similar ring with three projections, fitting into the upper thimbles and keeping up the whole.

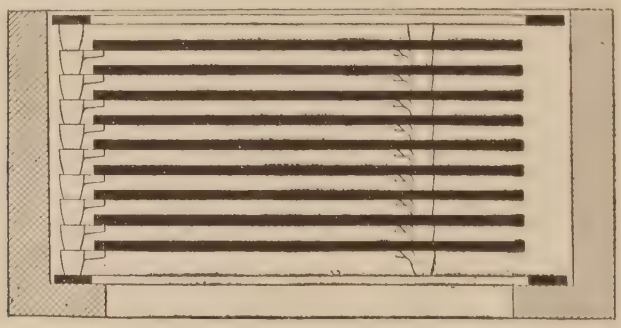


FIG. 295.—Method of Filling a Sagger.

In the preceding methods of saggering the pieces lean on the saggers or on the supports. They can also be made to rest on one another by separating them by little triangular pieces having three lower points and one upper one, called by the name of *cock-spurs* (Fig. 296). In the same way for that purpose pins that are not let into the walls can be used. Lastly,

in some cases the pieces, especially plates, can be placed upright in rectangular saggers, kept up at the bottom by triangular saddles and at the top by a series of thimbles. This arrangement is shown in Fig. 297.

We could multiply examples, because the methods used depend entirely on the shape of the ware, and can be infinitely

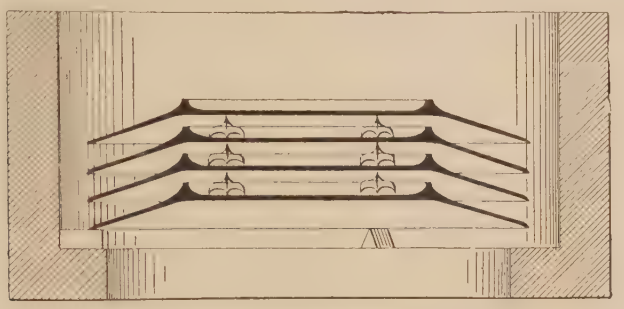


Fig. 296.—Method of Filling the Sagger.

varied in details. The foregoing ones will suffice to show the principles on which the saggering of faience is based. All these supports for burning or *stilts* have been given a series of names which the shape of them has suggested to the fancy of the workmen; simple pins, cut off ones or with a top, simple or double spurs, stilts with three or six points, thimbles, butterflies, easels, etc., etc.

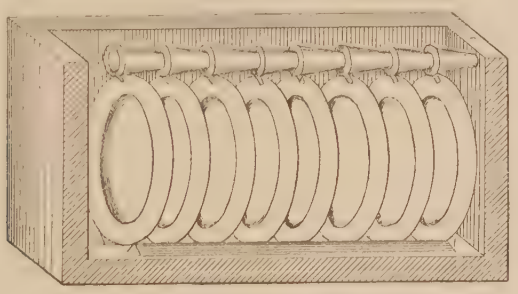


Fig. 297.—Method of Filling the Sagger.

These sundries, made of fireclay, are stamped out of firm body by means of small lever presses worked by hand. A machine of this kind is shown in Fig. 108 (page 228). It is usually best to buy them of special makers.

**265. Decoration.**—All the methods of decoration which were

described in Chapter VIII. can naturally be used for faience. We will only repeat those which are most frequently used.

The bodies are seldom coloured on purpose, but they are so too often in nature, by the small quantity of oxide of iron that clay always contains. However, they have often imparted to them an ivory tone that is very agreeable.

The *coloured slips* are sometimes used for making backgrounds, they are then generally put on with a brush to the unburnt body. The bands or borders on plates are easily done by making the ware turn round on a wheel in front of a brush that is kept in one position. The slips are manufactured by adding colouring matter (Art. 189) to the body. As the proportions of the colouring materials that must be added are usually somewhat large, the composition of the body must be modified so that the shrinkage may be the same. For this purpose an addition may be made either of plastic clay or of flint, correcting the diminution of the fusibility by a little feldspar. The composition of these slips varies thus with that of the bodies, and it is impossible to give more exact details on this subject.

The *under glaze colouring* is the method of decoration that is most used, especially for table ware. At the present time decoration by printing is almost exclusively made use of (Art. 191), the painting with a brush being only used for making bands, backgrounds, or to lighten the designs obtained by monochrome printing.

The following are some examples of the composition of the most usual colours :—

*Blacks.*

| | |
|---|---|
| Oxide of iron | 44 |
| Oxide of lime | 44 |
| Oxide of manganese | 10 |
| Oxide of cobalt | 2 |

(This mixture is burnt, then washed.)

| | |
|---|---|
| Sulphate of iron | 56 |
| Bichromate of potash | 28 |
| Oxide of manganese | 10 |
| Oxide of cobalt | 6 |

(The first two substances are heated together, the others are added to them, then heated afresh and washed.)

*Blues.*

(Oxide of cobalt, in proportion varying with the depth of colour, mixed with a little flint and carbonate of lime.)

| | |
|---|---|
| Precipitated oxide of alumina | 70 |
| Nitrate of potash | 10 |
| Oxide of cobalt | 20 |

(Well wash the alumina, mix together and heat.)

| | |
|---|---|
| Ammoniacal alum | 80 |
| Oxide of zinc | 12 |
| Oxide of cobalt | 8 |

(Heat and wash.)

*Bluish Green.*

| | |
|---|---|
| Flint | 22 |
| Borax | 22 |
| Oxide of zinc | 20 |
| Oxide of chrome | 16 |
| Oxide of cobalt | 8 |

(Frit them.)

*Greens.*

| | |
|---|---|
| Flint | 66 |
| Borax | 13 |
| Carbonate of lime | 1 |
| Oxide of chrome | 20 |

(Melt a part of the flint with the borax, complete the mixture and heat it again.)

| | |
|---|---|
| Flint | 32 |
| Borax | 42 |
| Oxide of zinc | 11 |
| Oxide of chrome | 11 |
| Oxide of cobalt | 4 |

(Frit them.)

*Yellows.*

| | |
|---|---|
| Oxide of lead | 17 |
| Oxide of tin | 66 |
| Oxide of antimony | 17 |

(First calcine and then mix the oxide of antimony.)
(For the deepest ground and orange, oxide of iron is added.)

| | |
|---|---|
| Oxide of lead | 41 |
| Oxide of tin | 21 |
| Oxide of antimony | 28 |
| Oxide of iron | 10 |

(The same as above.)

*Red.*

| | |
|---|---|
| Oxide of zinc | 50 |
| Carbonate of lime | 25 |
| Flint | 18 |
| Bichromate of potash | 3 |
| Borax | 4 |

(The following fluxes are added when heated.)

| | |
|---|---|
| Red | 70 |
| Feldspar | 10 |
| Borax | 16 |
| White lead | 4 |

(Then it is heated again at a low temperature.)

*Browns.*

| | |
|---|---|
| Sulphate of iron | 38 |
| Oxide of zinc | 38 |
| Bichromate of potash | 24 |

(Heat and wash them.)

| | |
|---|---|
| Chromate of iron | 50 |
| Oxide of manganese | 50 |

*Violet (unique).*

| | |
|---|---|
| Oxide of tin | 100 |
| Boracic acid | 10 |
| Oxide of cobalt | |
| Bichromate of lead | 1·5 |

(Heat them and add 20 per cent. of white lead. For the dark tones add oxide of cobalt.)

For decorating by printing these powder colours are added to the printing ink; when put on with a brush gum tragacanth or glycerine is added to them.

The colourless glazes, the composition of which has already been given, are nearly always applied by immersion for table ware. It is tinted sometimes with a little oxide of cobalt when they wish to neutralise the yellowish colour of the body.

*Coloured glazes* are often used also for decorative objects. They are composed of a colourless glaze, with the addition of colouring oxides, and sometimes with a certain proportion of oxide of lead, which increases the brilliancy of the colours, but easily makes them run. The colouring oxides are mixed in the proportion of 3 to 12 per cent., according to the shade wanted and the colouring power of them. Colourless glaze can also have the preceding under glaze colours mixed with it.

Faiences when done with under glaze decoration, or with coloured glazes, are burnt in saggers in ordinary kilns.

Lastly, *over glaze colouring* can be used for them by means of vitrifiable colours, which are burnt in muffles. This method, less employed for faiences than for porcelain, will be mentioned in Chapter XIII. (Art. 294).

**266. General Arrangements of Faience Works.**—The manufacture of faience is at the present time concentrated in a relatively small number of large works. In England nearly all the faience works are situated in the north of Staffordshire, round the towns of Hanley and Stoke-on-Trent. The clay is found on the spot as well as the coal. Kaolin and pegmatite, which come from Cornwall, are brought by sea. It is the same with the flint, which is burnt and ground at Runcorn and Newcastle-on-Tyne. The port for Staffordshire is Liverpool, the powerful commercial movement of which has helped a great deal towards the exportation of English faience.

France, Germany, Belgium, and Austria also possess important faience works doing an export trade. In other countries where there are some factories the sale is purely local.

The reasons that dictated the placing of these faience works are complex. Mostly they are found near the beds of plastic clay, and as near as possible to the coalfields. At other times they are placed in localities particularly favourable for cheap transport. Lastly, sometimes they are put near the large centres of consumption.

Faience works are composed of buildings in stories, on the ground-floor of which are the workshops for the preparation of the bodies, the manufacture of the saggers and the muffles. The moulding and decorating are generally on the first and second floor. The kilns are either outside, or else, what is more convenient, placed under a large closed shed which communicates with the other buildings. Other smaller sheds contain the supplies of raw materials and manufactured ware. Lastly, an important place is necessary for the accessories: forge, workshop for repairing, pattern shop, warehouse, etc.

# CHAPTER XII

## STONEWARE.

SUMMARY.—Classification.

SEC. 1. *Stoneware properly so called:* (*a*) *Paving Tiles:* Forms and Dimensions—Composition—Colouring—Methods of Manufacture—Manufacture in Plastic Body and in Dry Body—Inlaid Tiles—Tests for Paving Tiles. (*b*) *Pipes:* Forms and Dimensions—Composition—Moulding—Burning and Salting—Tests for Pipes. (*c*) *Sanitary Ware.* (*d*) *Stoneware for Food Purposes and Chemical Productions.* (*e*) *Architectural Stoneware.* (*f*) *Vases, Statues and other Decorative Objects.*

SEC. 2. *Fine Stoneware.*

**267. Classification.**—We have seen that stoneware (Fr. *Grès*)[1] is an opaque impermeable ware, with a coloured body, although it is often only slightly yellowish, greyish, or bluish. It is dull or covered with glaze. The impermeability of the body distinguishes it from terra cotta and faience ; its opaqueness makes it differ from porcelain.

According to this definition, the distinctive characteristics of stoneware are impermeability and opaqueness. At first sight, these words denote two physical properties of the material, easily understood and closely defined. But, if it is desirable to specify the terms by indicating the characteristics by which it can be recognised that a ware is impermeable or opaque, we remark that the question is not as simple as it looks, and that absolute properties are not present, but only relative properties, in which understanding plays a part. As regards the opaqueness, that will be discussed when speaking

[1] This name has been given to them in consequence of their colour, which is generally of a blue grey, similar to that of some natural stones. From the High German *griez*, German *gries*, gravel Brongniart added to the word *grès* the adjective *cérame*, to prevent confusion. That not being possible in a work devoted to pottery, we have not thought it necessary to use it.

of the classification of porcelain; we need now only define what is meant by impermeability. Absolute impermeability exists in bodies in which the material exactly fills the volume occupied. Such are, for example, metals and glasses that have no defects. In that sense, this absolute impermeability does not exist in pottery. In all ceramic productions, even when completely vitrified, the density measured in powder finely ground is higher than that observed in broken pieces. The difference shows the proportion of the empty spaces. If we wish to measure the permeability of a body by the weight of the liquid that can be incorporated in it, we easily see that this depends entirely on the conditions of the experiments. Porcelain and stoneware when perfect can often, when in the form of pieces, be plunged indefinitely into water without increasing in weight; but that would not be so if, by more powerful mechanical means, one could fill with water the pores that they contain; for example, by submitting them several times and alternately, in the vacuum of a pneumatic machine and to a considerable pressure of water. In working by simply immersing it in water, at the pressure of the atmosphere, we may remark that wares which do not show any noticeable increase in weight at the end of some hours, do show it, however, after several months. This fact is found even with wares decidedly porous which increase indefinitely in weight, that the increase naturally becomes always more and more feeble. The weight of water absorbed has a tendency to correspond with the volume of the spaces, measured by the difference in the densities of the powder and the broken pieces, but without ever attaining that limit.

We see then that the impermeability of pottery is always relative, that it depends upon the conditions and length of the experiment. Besides, if we operate on a continuous series of wares, passing insensibly from terra cottas and faiences to stoneware and porcelain, the proportion of water absorbed diminishes more and more, then is annulled, but without it being possible, at any moment whatever, to trace the limit between permeable and impermeable ware. We may imagine, however, that in certain cases, for the application of the Custom House duties for example, they have tried to fix a maximum amount

of water that can be absorbed by a ware, under definite circumstances, so as to distinguish the stoneware from terra cotta. Thus we have the advantage of possessing a precise method of taking the first that comes to hand, but this method can only have a relative value from a ceramic point of view. From that point, it is convenient to reckon as stoneware all pottery that is opaque, the body of which is vitrified, thus becoming almost impermeable, before it gets out of shape. It happens somewhat frequently that wares made with the bodies suitable for stoneware are still too permeable to be able to be reckoned commercially as stoneware, because the burning has not been carried to a high enough temperature, but, ceramically, they are none the less stoneware bodies. It also happens, on the other hand, that, since stoneware has become the fashion, this name has been given to wares that are not so, but which, by their uses, are almost suitable for the same purpose. This observation applies to certain pipes with a fireproof body which is relatively porous, and has only acquired impermeability by the saline glaze. It includes also certain paving tiles, which, if melted, would only make scoria, but which are, nevertheless, only slightly permeable and are very hard, an essential quality for this class of goods. As these wares are manufactured by the same methods as true stoneware, we will examine them in this chapter, though we do not hide the fact that this classification is theoretically incorrect. Brongniart, and, after him, nearly all authors, have divided stoneware into common stoneware, the body for which has as a basis a vitrifiable clay, of which the glaze is saline, and into fine stoneware, having a body and glaze similar to those for feldspathic faience. It seems to us that this classification corresponds exactly to the reality of the actual facts. Doubtless the stoneware which is named fine, the manufacture of which has not been noticeably modified or extended since Brongniart's time, has a composition, and especially methods of manufacture, which distinguish it fairly distinctly from the other kinds; but the latter has been considerably developed, and certainly will become of more and more importance in the future. It no longer is used solely for making jugs and pipes, it will take other glazes

besides the salt glaze, and may be used as decorative ware which can from this time be classed among the most beautiful ones that the ceramic art can produce. Under these conditions, the epithet of common with which they have been designated has lost its meaning, and would give rise to the same errors and the same objections that have been caused as regards the faiences. We think then that if, in the absence of any other term and on account of its being the one generally used, we are obliged to continue to class the fine stoneware by this name, it is necessary to suppress the adjective common for the others. We will consider them simply as stoneware, that is stoneware properly so called.

The classification adopted in this chapter, then, will be the following :—

1. *Stoneware properly so called,* with a coloured body, although sometimes only slightly bluish or yellowish, argillaceous, prepared in a pasty or dry manner, according to the methods employed for manufacturing terra cottas. The principal varieties are the following :—

(*a*) *Paving tiles,* which are used either for pavements or for the walls, usually dry, of a single colour, or else decorated with slips of different colours.

(*b*) *Pipes* used for conveying liquids, with a salt glaze.

(*c*) *Sanitary ware,* used in the construction of buildings and for domestic purposes ; these are either dry, salt glazed, or more often with an alkaline plumbiferous and stanniferous glaze.

(*d*) *Stoneware for food purposes and chemical productions,* either dry or with a glaze that is usually saline.

(*e*) *Architectural stoneware,* either dry or with various glazes.

(*f*) *Vases, statues and other decorative objects* of a similar kind to the preceding.

2. *Fine stoneware,* of a white or coloured body, argillaceous and kaolin nature, prepared in a liquid method according to the processes used in the manufacture of feldspathic faience, either dull or covered with an alkaline-boracic plumbiferous glaze.

### 1. *Stoneware Properly so Called.*

#### (*a*) *Paving Tiles.*

**268. Forms and Dimensions.**—The stoneware tiles and those which are sold as such are of somewhat varied shapes, which are explained by the different uses to which they are put and by the variable quality of the body.

For lining walls and for the inside pavements, square or

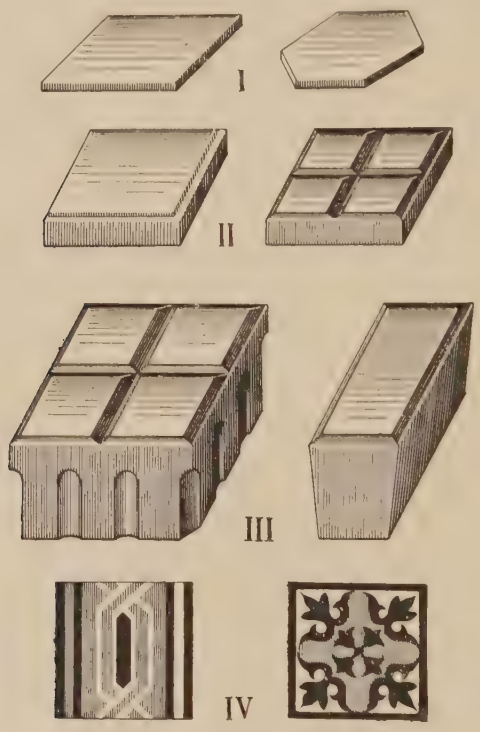



Fig. 298.—Tiles.

hexagonal tiles are generally used, type 1 (Fig. 298), the largest size for which is scarcely above 9 ins., and may be as low as 4 ins. The thickness, which is more reduced the better the quality of the body, varies from $\frac{1}{4}$ to $\frac{1}{2}$ in. They are entirely of one colour: white, red, brown, black, or sometimes yellow.

For the paving of footpaths, porches, stables, etc., square tiles are used (type 2), united or striated, about 5·6 to 7·6 ins. side, and 1·2 to 1·6 in. thick. They are entirely of one colour: yellow, brown, red, or black.

For pavements that have to bear a great deal of wear it is best to make them thicker; then shapes similar to those shown in type 3 are generally adopted.

Finally, the tiles can be decorated with coloured slips applied by inlaying, as shown in type 4. In that case they are generally square, of from 6·0 to 6·8 ins. side, although, according to the design that they are to bear, they can be of other shapes. The thickness varies from ·6 to ·8 inch.

**269. Composition.**—The composition of the body is somewhat variable; sometimes a vitrifiable clay either more or less thinned is used, sometimes a fusible clay is made more fireproof; lastly, a fireproof clay is made vitrifiable. We will now examine these different cases.

*The Use of Vitrifiable Clays.*—We saw (Art. 31) that the vitrifiable clays vitrify more or less completely in the porcelain firing, but that they remain almost dull in faience firing. They contain a certain proportion of fluxes, alkalies, lime, and oxide of iron. This last, however, is nearly always in the form of peroxide, and consequently can only play the part of a flux if the burning is done in a decidedly reducing atmosphere, which turns it into the form of protoxide. We may then set it down that all vitrifiable clays containing some iron are more fusible when the burning is done with a reducing working than when it is oxidising. In the latter case we can only count on the alkalies, lime, and magnesia to cause vitrification. Generally the proportion of lime and magnesia is not high, it scarcely ever is above 1½ to 2 per cent. altogether.

On the contrary, the amount of alkali is not below 2½ or 3 per cent., and may be as high as 5 and 6 per cent. We have seen that, according to the works of M. Vogt, these alkalies closely mixed with the hydrosilicate of alumina, which is soluble in concentrated sulphuric acid, are in the form of mica in the state of an impalpable powder.

On the other hand, the vitrifiable clays are almost always rather plastic; it is seldom that the proportion of alumina falls below 25 per cent., and it sometimes rises above 30 per cent. Under these conditions, the lime and magnesia, when the carbonates are decomposed, and the alkalies, at the temperature

for fusing the mica, being in an impalpable state in the whole mass, may cause it to soften and warp at the same time as it vitrifies. It is then generally necessary to add to the body a certain proportion of silica, which serves as a stiffener and allows it to begin to vitrify without the goods getting out of shape. The coarseness of the grains of silica is of very great importance: if too fine, they have a tendency to be rapidly got rid of when the body fuses; if too large, they prevent it from becoming impermeable. We see that the composition of the bodies for stoneware, when made with vitrifiable clays, can only vary in somewhat narrow limits.

The following are the quantities that may be put down as medium ones:—

| | Per Cent. |
|---|---|
| Silica . . . . . | 68 to 75 |
| Alumina . . . . . | 20 ,, 25 |
| Lime and magnesia . . . . . | 10·5 ,, 2 |
| Alkalies . . . . . | 3 ,, 5 |

In some cases there must be added to the foregoing numbers a somewhat high proportion of oxide of iron, which may reach as high as 10 to 15 per cent.

*The Use of a Mixture of Fusible Clays and Fireproof Materials.*—It can be easily understood that by adding some fireclay to the fusible clays, and, if needed, some silica also, a vitrifiable body similar to the preceding ones can be obtained; yet, considering that the fusible clays usually contain much more lime than alkali, the vitrification in that case occurs at the time of the decomposition of the carbonates, that is to say, at a lower temperature. It must be remarked on this subject what a wide difference exists in the way in which lime and alkalies act. As for lime, at the moment at which the temperature for decomposing the carbonates is reached, it has a tendency to form quickly through the whole mass a double silicate of alumina and lime, perhaps also some aluminates of lime, so that, in spite of the silicious strengthening, it softens a short time after it begins to vitrify, and the ware may quickly get out of shape. With alkalies, on the contrary, in the form of mica or feldspar, the action commences with the fusion of these rocks, and it is only progressively that the little grains of flux enter into combination with the molecules of silica and alumina that

surround them. The time then is fairly long between the commencement of the vitrification and the moment at which it loses shape. For bodies of this description the proportion of alkalies scarcely exceeds 2 per cent., while that of the lime rises as high as 6 to 10 per cent., the amount of silica and alumina remaining the same, although the relative plasticity of the carbonate of lime would allow of less aluminous bodies being used.

*The Employment of a Mixture of Fireclay and Fluxes.*—The forms in which the fluxes are added to a fireclay are very various. It is just the same with the proportion of them, because the latter depends upon the coarseness of their grains.

The mixture which gives the best results is the addition to a fireclay that is suitably thinned of some feldspar or pegmatite finely powdered. By giving to the body the composition that was indicated for the bodies of vitrifiable clays and 5 to 6 per cent. of alkalies, stoneware can be obtained of a very good quality that will resist for a very long time without losing shape, because the fluxes are in a coarser form, whatever the fineness to which they are powdered, than those in the natural clays.

Unfortunately this method is rather costly for goods that are not of a high commercial value. Alkalies can also be employed in the form of salts, but then the vitrification takes place at a low temperature, and has almost the same disadvantages as with lime. For economical reasons calcareous fluxes are very much used. For this purpose, calcareous clays, marls and carbonate of lime can be made use of; but the substance that has given the best results is the slag from the blast furnace, which is a somewhat impure silicate of lime.

The bodies thus obtained have somewhat the following composition:—

| | |
|---|---|
| Silica . . . . . | 51 to 55 |
| Alumina . . . . . | 19 ,, 22 |
| Lime . . . . . | 22 ,, 25 |

plus a small quantity of oxide of iron, oxide of manganese, magnesia and alkalies. The tiles made with bodies of this class are always slightly permeable, as they can only be burnt up

to the commencement of vitrification without risking a rather sudden loss of shape. Even when melted, the body does not become impermeable, so that, ceramically speaking, these wares, as a general rule, are terra cottas rather than stoneware.

Sometimes, more or less open fireclays have been mixed with rather coarse broken glass. The body when burnt does not then have a homogeneous look; it is composed of fireproof parts united to other vitrified parts. If it were carried to a fusing point, the marl would remain heterogeneous, and pieces of clay and silica would be found incorporated in the vitreous flux. Glass cannot be used in a fine powder, because then the softening would take place at the same time as vitrification.

Finally, it would be advisable to mention the tiles called pyrogranites, manufactured in Russia, composed of a fireclay mixed with a fusible clay, the burning of which is carried on to the fusing point in fireclay moulds. The originality of these wares consists especially in the polish imitating that of hard stones, which is given to them by passing them through a mill. However, all impermeable wares are also capable of being polished; but in the tiles of which we are speaking, the introduction of grains of terra cotta of different colours produces on the surface marble in imitation of granite.

**270. Colouring.**—In the chapter relating to burning (Art. 147) we discussed the part played by oxide of iron in the colouring of the bodies, yet it is necessary to complete what was said by some observations peculiar to stoneware.

The colouring of these wares is very variable. Sometimes only slightly yellowish or bluish, they are frequently of a bluish grey (pearl grey), darker or lighter, at other times yellow, red, brown, or black. Except in the cases, which are always very rare, in which the bodies contain oxide of manganese, these colours are due to oxide of iron and to the way in which they are fired.

The white colour only slightly tinted can only be imparted to them by vitrifiable clays containing very little iron. These clays are extremely rare, for, as we have already observed, the lowest proportion of iron at the moment of vitrification is sufficient to colour it. Generally, white stonewares are obtained by a mixture of white fireclay, kaolin, and alkaline fluxes.

The same as in terra cotta, the grey or bluish-grey colours arise from a body containing a little iron and burnt in a reducing atmosphere. In order to be sure of obtaining these colours, it is wise to burn with a reducing working above a temperature of 800° C.

The yellow colourings are given by the bodies containing very little iron, or by calcareous ferruginous bodies heated in an oxidising fire during the whole of the burning process. Under those same circumstances the bodies that are simply ferruginous become brown, or even black, when the proportion of iron is very high. The decidedly red colour is much more difficult to get in stoneware than in terra cotta; it is necessary for the body to contain a great deal of peroxide of iron, a little alkali, no lime, and that the burning, which naturally would be in an oxidising atmosphere, should be stopped when vitrification begins. Lastly, the uniformly black colour can, when oxide of manganese is not used, only be really produced by a reducing working and a deposit of carbon in the pores of the ware before it vitrifies. In that case the method indicated for the manufacture of black tiles can scarcely be used, because it would be difficult to keep a suitable working above 800° C. up to the time of vitrifying. It is preferable to enclose the ware in saggers filled with powder carbon in the form of charcoal or coke (Art. 220).

**271. Methods of Manufacture.**—Stoneware tiles can be manufactured by two processes: moulding the body in a plastic state, or moulding them with more or less dry powder. In the first case the process can be used that was described for terra cotta paving tiles (Art. 221), but by always pressing the tiles again afterwards, when they have been sufficiently dried, in order to lessen as much as possible the spaces that are found in the body in consequence of the evaporation of the water. This process, which it is useless to describe at greater length, can only be used to make fairly thick tiles of a relatively moderate quality.

In order to get very thin and very hard tiles one has recourse also to moulding in plastic clay, but by using for this operation all the care in quite as particular a manner as that which will be described in the following article.

For thicker tiles, which are intended principally for paving,

they make almost exclusive use of moulding in a press with more or less dry powder. This process will also be described further on.

All the tiles of which we have just spoken are entirely of one single colour. Tiles ornamented with designs in polychrome are also manufactured, called by the title of inlaid tiles, which are certainly one of the most beautiful pottery manufactures. In this case the moulding is now done almost exclusively by means of dry body reduced to powder and variously coloured. They will be discussed in Article 275.

**272. Manufacture in Plastic Body.**—The bodies used for this

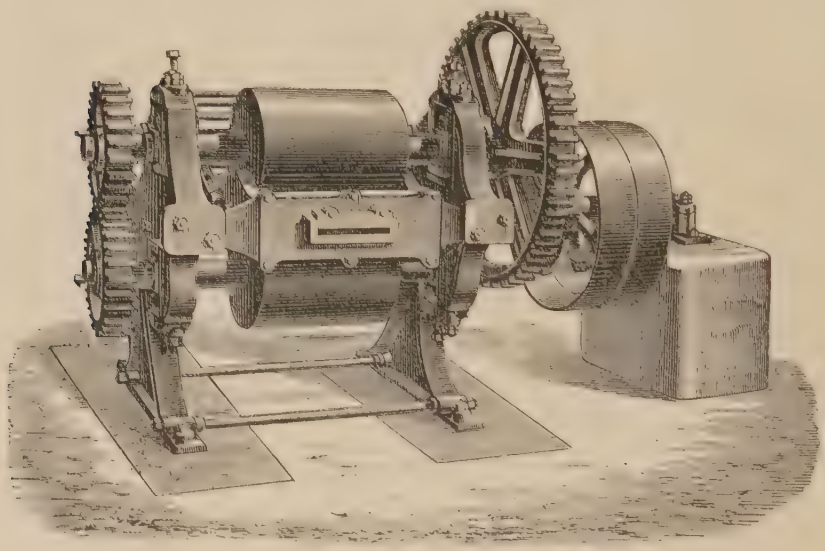


Fig. 299.—Machine for Expressing Tiles.

manufacture are generally rather plastic and with alkaline fluxes. White vitrifiable clays are mostly used for white tiles, ferruginous clays for red or brown ones. As for black tiles, they are coloured either by manganese, or more often by being burnt in a sagger containing carbon.

The preparation of the body is done in a soft pasty manner or else by pulverisation. Washing is often resorted to for purifying the raw materials. Moulding, which is the characteristic operation of this manufacture, needs several special operations. They begin by expressing cakes of body by means of cylinder propellers. Fig. 299 represents a machine for making a large

quantity that makes 1,500 pieces of medium size per hour. Fig. 300 shows a similar machine worked by hand, with a production of 400 pieces. When coming out of the die the prism of body is received on a fixed cutting table (Fig. 301). It passes first under a roller, on the two sides of which are stretched vertical wires, which cut it to the required width. The lengthway cut is done by a series of transverse wires, as in the similar apparatus already described. Lastly, the tiles

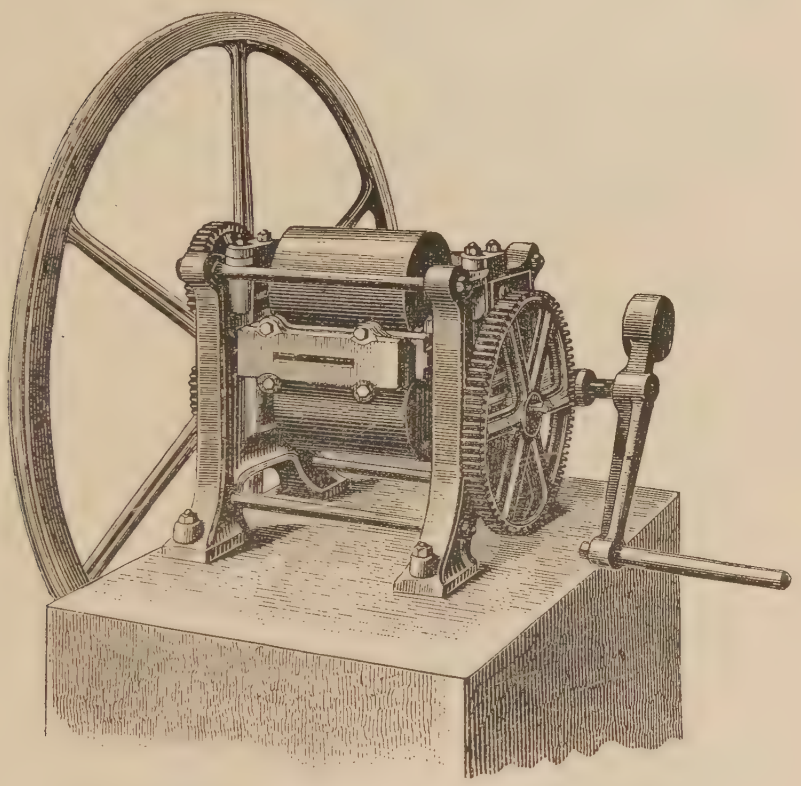


Fig. 300.—Machine for Expressing Tiles.

thus cut pass under a last roller, the object of which is to beat down the ridges caused by the cutting. When the tiles are hexagonal, they are cut on a special table with bands of the width desired, and a special cutting apparatus, shown in Fig. 302, is put over them.

The tiles when cut thus are piled up, as we said in the preceding article, until they have acquired the consistency of a firm body. When the body is not naturally of the required

colour, or, at least, when it is not of the intensity that is desirable, it is usually immersed in slip. This slip dries rapidly

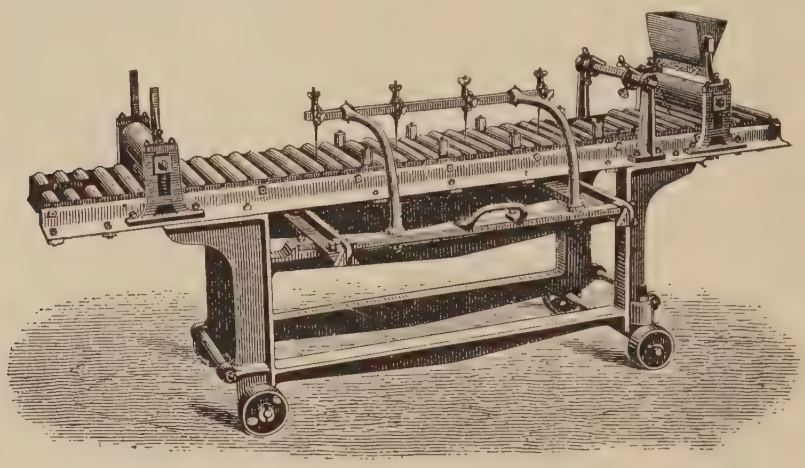


FIG. 301.—A Cutting Apparatus for Tiles.

and allows of it being beaten out after a little time. This latter process is done by hand by placing the tile on a marble

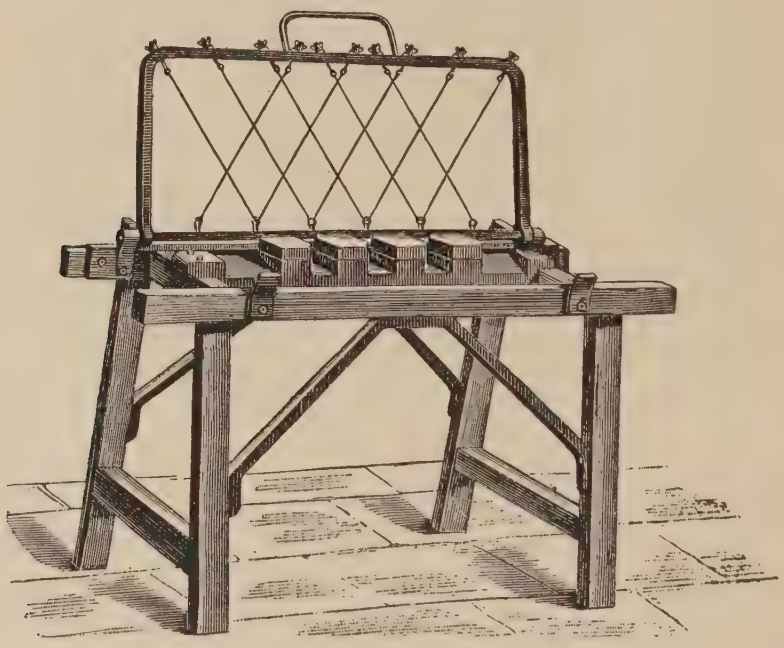


FIG. 302.—An Apparatus for Cutting Tiles.

slab and striking it on both faces, but especially on the face that is to show, with a wooden bat. This operation being

finished, the tile is put between two rolling mills set in motion by a crank (Fig. 303), the lower of which is in cast iron furnished with grooves and the upper of polished bronze. The object of this machine is to striate the lower face of the tile so as to make it adhere more easily to the bed of mortar, and to polish the upper face. It remains then to give the tile a regular shape; for this purpose the templets can be used, or else a special machine can be resorted to, but this is better for large quantities. Fig. 304 shows a tool of this kind. The tile, being conveniently placed on a lower slab, is trimmed by 4 or 6 edges according to its shape; these in

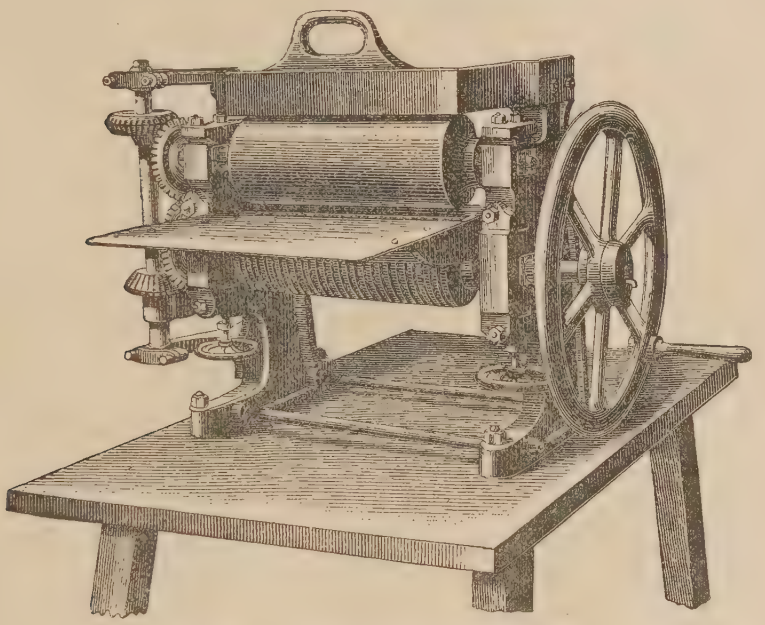


Fig. 303.—A Machine for Polishing Tiles.

their descent cut it obliquely so as to give it the truncated pyramidal form that is wanted, then they separate so as not to carry up the tile as they ascend. The production of these machines varies from 200 to 300 tiles an hour according to their size. The finished tiles are raised from the slab and put in piles to finish drying. All the machines of which engravings are given in this article are made by MM. Chavassieux-Long. The method of moulding just described is that which answers to the most careful manufacture; sometimes it can be simplified, but at the expense of the quality of the goods.

For small quantities the burning is done in intermittent kilns. For this purpose muffle kilns are frequently used of the type shown in Fig. 179 (page 377). For larger quantities it is better to make use of kilns heated by gas. A clever manufacturer of Beauvais, M. Colozier, has succeeded in burning hard tiles in a kiln with continuous firing of the type shown in Fig. 262 (page 529); yet we think that, as others have done, it is

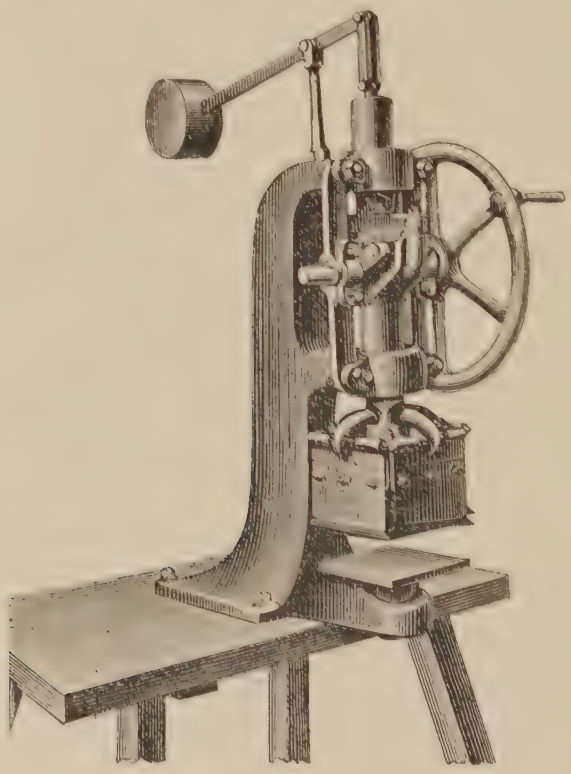


Fig. 304.—Machine for Trimming Tiles.

more convenient, although less economical, to use continuous kilns with several burning spaces (page 677).

Whatever the type of kiln used, it is essential to have a very slow smoking and a very careful one, by means of special fireplaces. Besides this difficulty in the smoking and the slow firing, a fresh one is encountered during the burning in consequence of the shrinkage, often considerable, which takes place in the body when being burnt at a temperature near that for vitrifying them. The charging being necessarily in "bungs," these have

a tendency to tumble over if the heat is not very uniformly spread over them. This defect often necessitates the charging being done in special ways, using special devices.

Hard tiles are manufactured in special factories. They exist in France at Beauvais and the neighbourhood, and in the south, at Marseilles, Aubagne, Salesnes, Apt and Orange. This manufacture is certainly one of the most careful and most difficult that is met with in pottery.

**273. Manufacture in Dry Body.**—This manufacture is much simpler than the preceding one, but it does not allow of such thin goods being made. It is therefore particularly suitable for the tiles for paving footpaths and streets. All the kinds of bodies already described may be used, and the same applies to the methods for colouring; it is therefore needless to return to this subject.

Whatever the raw materials, the preparation is by the dry method, yet certain substances, such as feldspar and pegmatite, are pulverised in water by preference in block machines, or else with Asling cylinders. The body that is being pulverised at the degree of moisture desired is moulded by means of hydraulic presses. The arrangements include the pump, the condenser and the press. The pump can only be worked by hand in very small factories; it is better in any case to make use of pumps with machine power. The condenser is not indispensable, but it would be inadvisable to do without it if regular quantities are wanted. Mostly, even two condensers are used, one at low pressure, that is to say, from 50 to 90 atmospheres, and the second a high pressure one, giving 200 to 250 atmospheres.

The moulding is generally done in the following manner. The body in powder is put by hand into the mould, using for it a sort of hopper with a definite capacity. A little pressure is given to it sometimes, either by hand or by machine, after which the mould is placed under the hydraulic press.

It is compressed first at a low pressure, then the compressed air contained in the body is allowed to escape, and it is afterwards acted upon at a high pressure. The moulding being finished the mould is drawn away, and is placed on an apparatus for taking it out of the mould, which generally consists of a

second hydraulic press, in which the water which served for the high pressure is made use of.

For small quantities two moulds on a slide, that are alternately under the press and being emptied, can be used, but the most usual arrangement consists in placing the mould on a slab revolving round one of the vertical pillars that hold the upper slab of the press. These moulds are then three or four in number, so that all the operations of the fashioning can be carried on at the same time. The working of the revolving plate is done by means of a little pump.

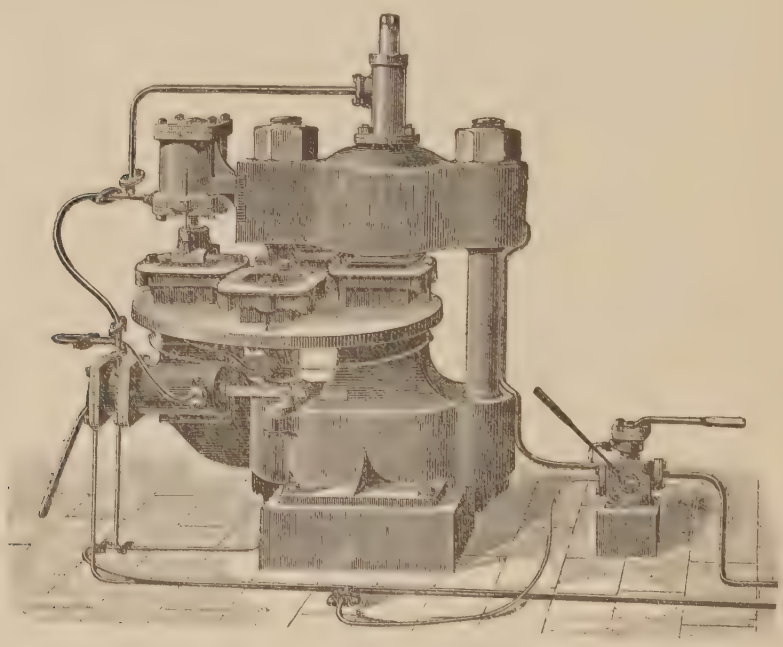


Fig. 305.—Hydraulic Press for Moulding Tiles.

The details of the machinery vary a good deal, according to whose make it is, and a description of them would be outside the scope of this work. We will content ourselves with reproducing in Fig. 305 a hydraulic press used for moulding tiles, made by MM. Desmarais et Cie. (Morane, senior).

The tiles when taken from the mould are hard enough to be taken up in the hand. They are then placed in drying sheds usually heated and ventilated by using, when possible, the waste heat from the kilns.

The charging is done in bulk, yet without the goods being able to be piled up above a height of $6\frac{1}{2}$ ft. to $9\frac{3}{4}$ ft.; if more than that, the lower rows would be crushed, when they softened, by the weight of the upper goods. Black tiles ought to be charged in saggers filled with carbon, as we said before. These saggers can be placed in the middle of other goods.

For small quantities the burning is done in round intermittent kilns with inverted flames, similar to those employed for burning fireclay goods, but less in height. The heat given off from the kilns when they are cooling is made use of in the drying sheds.

As soon as the production allows of it, it is more advantageous to use continuous kilns. For this purpose kilns with a single burning space have been made use of, but, in spite of the expenditure of fuel being greater, it seems better to use kilns with several spaces. The heating by gas, which is much easier to regulate, ought, as a general rule, to be preferred. Fig. 306 shows a kiln of this kind, invented by M. Mendheim, which is made on the principle indicated by Fig. 175 (page 374). Each chamber communicates with the following one by channels starting at a lower corner to go underneath the whole hearth and end in the next chamber. In that hearth are found also gas channels placed parallel to the air passages, so that the flames come up through a series of openings at the bottom. The gas is led into each chamber through an outside subterranean channel, while the draught is caused by a central passage for the smoke.

Some openings, arranged in the walls that separate the chambers, allow the working of fireproof dampers; lastly, channels placed along the domes serve for the smoking with the warm air, as we said, in Art. 206, when speaking about burning bricks.

The thermic balance-sheet of these kilns can be reckoned approximately as follows:—

| | | | |
|---|---|---|---|
| Heat produced by combustion . | 100 | Heat theoretically necessary . . | 55 |
| Heat given by collection . . | 30 | Heat lost by the heating of the walls . . . . . | 33 |
| | | Heat lost by radiation . . . | 15 |
| | | Heat lost through the chimney . | 7 |
| | | Heat lost in generating the gas . | 20 |
| | 130 | | 130 |

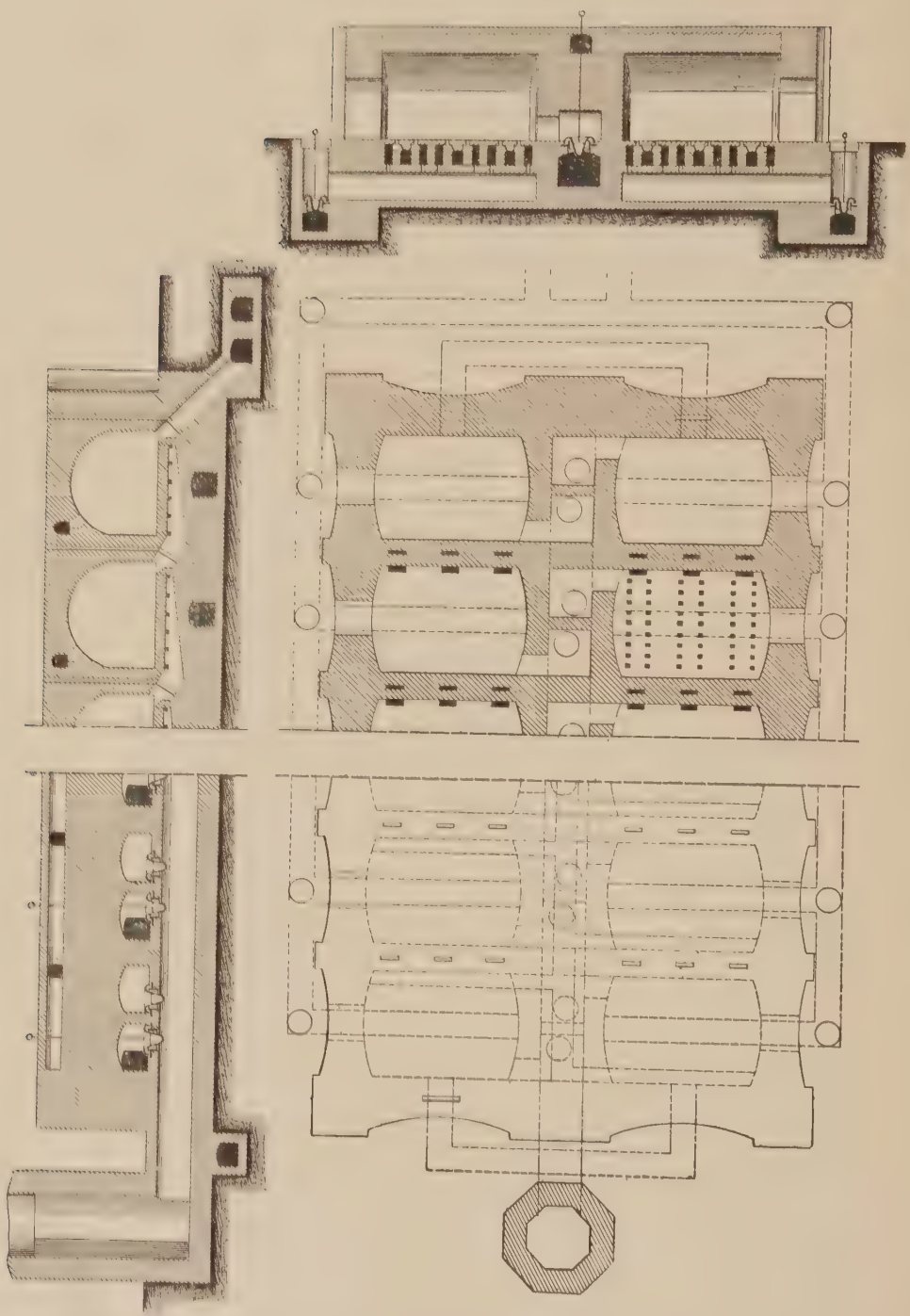


Fig. 306.—Kiln with Continuous Firing, with Several Chambers, Heated by Gas.

When they come out of the kiln the tiles ought to be sorted, and generally there are two or even three qualities.

The manufacture of these tiles needs very large works to be remunerative; it is only exceptionally that they are made as accessories in some tile and faience potteries.

**274. Inlaid Tiles.**[1]—The manufacture of inlaid tiles dates from 1861; since that time it has been greatly extended, especially in the north of France. The body can be a vitrifiable clay, or a fireclay with the addition of feldspar, and, when necessary, some silica. It is decorated by means of slips, applied by incrustation in the form of a powder. The tiles are generally square, with a side of 4·72 to 7·88 ins., the most usual size being 6·36 ins.; the thickness varies from ·669 to ·866 in. Half and also

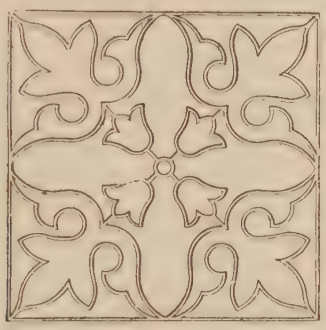


Fig. 307.—Templet for Inlaid Tiles.

quarter tiles are made, the latter being divided either rectangularly or on the diagonal. Borders have a rectangular form.

The slips are made by mixing colouring oxides in the body; it is needless to repeat on this subject what was said in Art. 188. Naturally the proportion of flux contained in the clay must be modified according to the fusibility of the colouring oxide. It is usually arranged for the slip to be a little more fusible than the body.

The applying of the slip dust at the time of making the tile is the distinctive and original feature of this manufacture. This operation is done in the following manner: a templet is placed in the bottom of the mould, that is to say, a little piece from ·032 to ·040 in. thick, formed of bands of copper soldered together, which divide it into cells having the shape of the

[1] Encaustic Dust Tiles.

outline of the design to be obtained (Fig. 307). When the mould is thus prepared it is passed to a series of workpeople, who each put a slip of a colour that has been decided upon

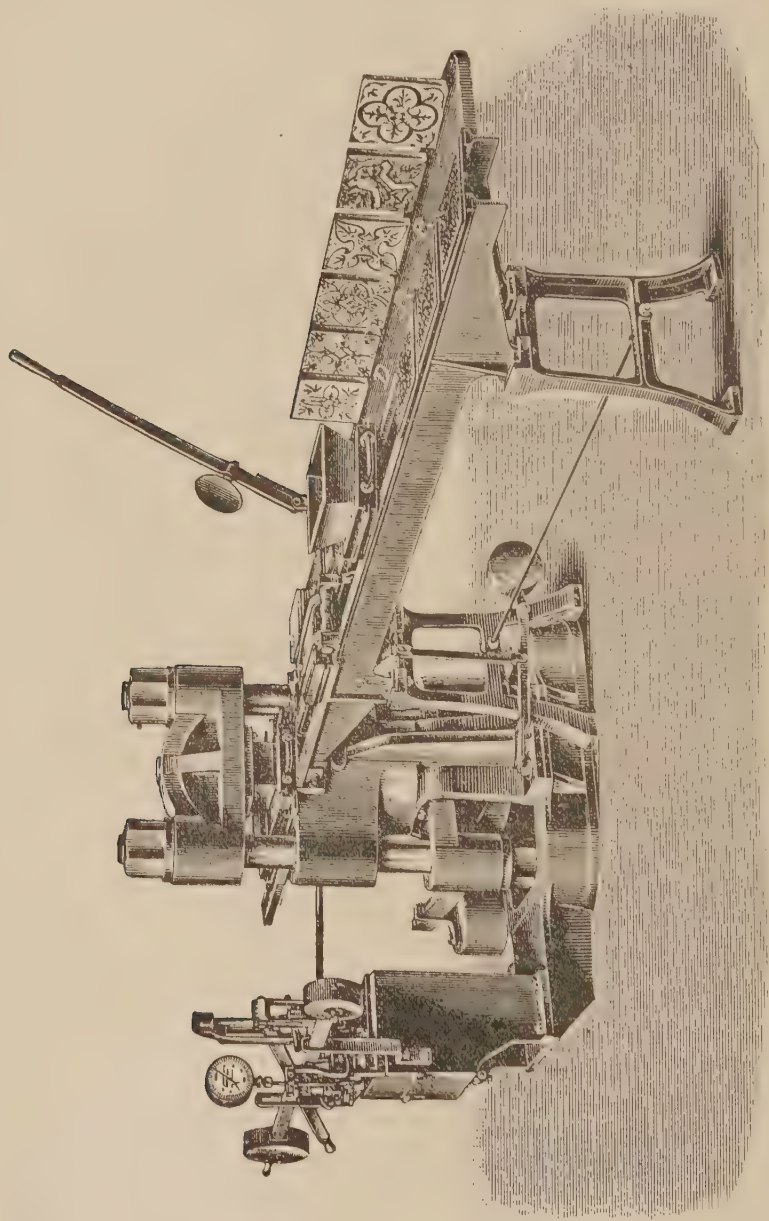


Fig. 308.—The Moulding of Inlaid Tiles.

into the proper cells. When all the templet has been filled, it is generally raised, a slight pressure is given to the slips by a chuck used by hand, then they continue to fill the mould

with ordinary pulverulent body. The whole is afterwards compressed in a hydraulic press, as we said before.

Fig. 308 represents a hydraulic press used for this class of manufacture. In the front is a table along which circulate the moulds, which are formed of two pieces put one on the other, the lower being the thickness of the slip, and the upper that of the body. On the front part of this table the slips are put into the lower part of the mould, as we have just described, then the upper part of the mould is put on, and it is filled with the body by means of a funnel; it is slightly pressed, the mould is

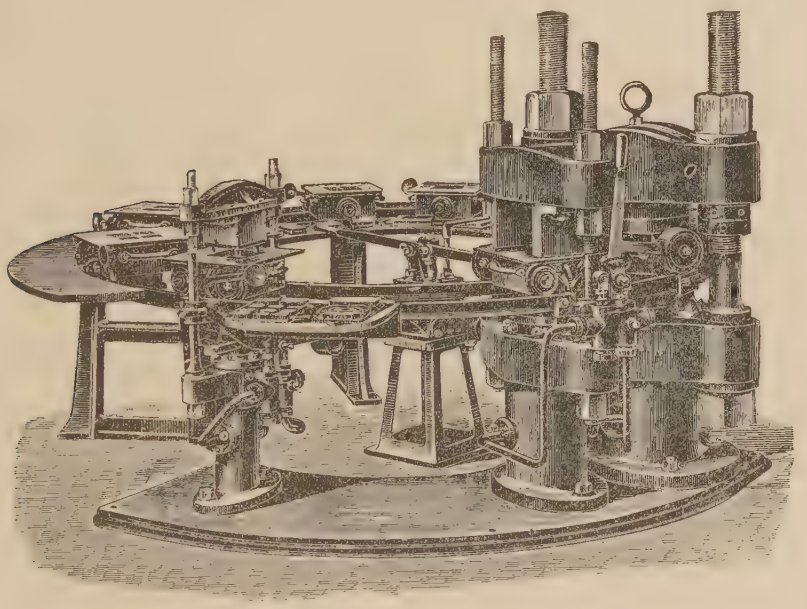


Fig. 309.—The Moulding of Inlaid Tiles.

covered over with a piece of cast iron or steel, and the whole is pushed under the hydraulic press.

For larger quantities a circular table is preferred, along which moulds are moved that run on rails. Fig. 309 represents an arrangement of this kind, the filling of the moulds being done by work-girls seated round the circular table; the whole working of the moulds and presses is attended to by a workman placed in the centre.

The drying of inlaid tiles is done in the same manner as smooth tiles, but the burning should be in saggers, the tiles being

saggered in bulk. Round kilns with inverted flames are generally used, but for large quantities kilns with continuous firing could also be made use of, as we said in the preceding article.

**275. Tests for Paving Tiles.**—Tiles can be submitted to two kinds of tests. Their permeability can be reckoned by first drying the tile at 110° C., then plunging it into water and measuring the increase of weight, at the end of twenty-four hours, for example. This increase is afterwards calculated as a percentage of the weight of the dry tile. There are no precise rules for making this experiment; what we have just said is only given by way of suggestion.

The determining of the resistance to wear is the essential test. Different machines have been proposed for calculating the diminution in weight or thickness that takes place in the tile when its surface is subjected to a lengthened period of use. The best way is to follow on this subject the conclusions of the Commission for the methods of testing building materials that were printed in Art. 231.

Tiles in true stoneware, when well made, offer a very great resistance to wear, quite equal to that of the hardest natural stones.

### (*b*) *Pipes.*

**276. Forms and Dimensions.**—Fig. 310 represents the most usual form of stoneware pipes, as well as examples of elbows, junctions, syphons, etc., employed in forming channels. The inside diameter varies from 2 ins. to 39 ins. Yet, in current use, it is seldom they are above 24 ins. The length of the straight pipes varies from 24 ins. to 39 ins.

The fitting of the joint with a layer of cement is the one most generally used. For channels where there is pressure it is better to make use of a joint with a collar (Fig. 310), which is also made air-tight by means of some cement put between the pipes and the collar.

**277. Composition.**—In the same way as for tiles, the best composition that can be given to the body of the pipes consists of a suitably thinned vitrifiable clay, or of a fireclay with the addition of feldspar or pegmatite. In this way perfect stone-

ware is obtained, very impermeable, resisting great pressure, the only defect in it being slight brittleness. For reasons of economy, the alkalies are sometimes replaced by a limestone flux, that is to say, a certain proportion of a fusible calcareous clay is mixed with a clay that is slightly vitrifiable, or with a fireclay. The ware obtained may be equally good, but as, according to what has been already said (Art. 269), they have a tendency to get out of shape, it is seldom that they can be burnt as high as to vitrify; the body then remains slightly permeable still.

Fireclays can also be used, or any at least that do not show any trace of vitrification at the highest temperature at which they are burnt. We have thus the advantage, as already said,

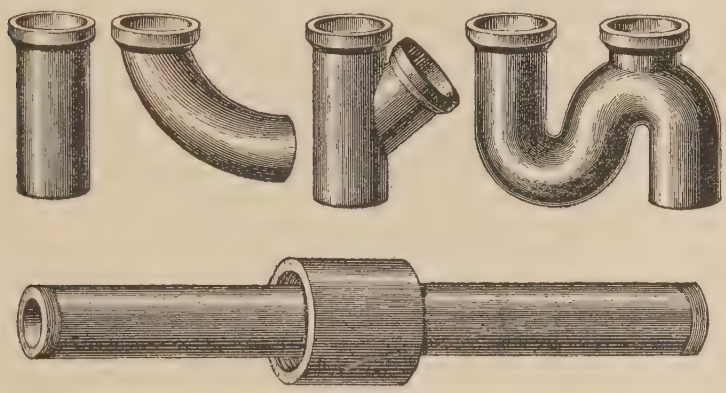


Fig. 310.—Pipes.

of obtaining goods which do not lose their shape, but the ware obtained by this process is still relatively porous, and we should not consider them as stoneware, at least from a ceramic point of view. English pipes, which are still so largely exported, are all included under this head.

The fireproof body must naturally contain more flux than the body used for the manufacture of fireclay goods, and the grain should be finer, so as to be suitable for the glaze. In some factories, especially in Germany, the body is covered over by a slip made with a fine vitrifiable body.

**278. Moulding.**—The preparation of the body is done, according to circumstances, either in a pasty manner or else by a dry method. As to the moulding, that is always done with plastic body.

Straight pipes can be made in three ways:—

1. On the potter's wheel.

2. By expressing the straight pipes and afterwards joining on the socket by hand, this socket being also made of a portion of a pipe that has been drawn, only of a larger diameter.

3. By expressing the pipes, the socket being made by machine.

The first method gives goods that do not look so well, in spite of the skill of the potter, and is more costly. The second is only suitable for making small quantities, the joints needing to be carefully done. The third method of moulding is the one employed in all important factories. As it is essential that the goods should not get out of shape by their own weight, which might easily happen in the large sizes, the pressing ought to be done vertically. The body, on coming out of a circular die, strikes against a chuck of the shape of the socket; owing to its plasticity it bends round it, then, when it has become of the desired shape, they let go the chuck, and the pressing of the straight part is accomplished as in other machines. When the pipe has reached the desired length the machine is stopped, it is cut with a wire, the pipe is raised with the little board on which it rests, and it is turned over so as to take the chuck away. Fig. 76 (page 200) represents a machine of this kind, made by M. Pinette, in which the body is compressed into a cylinder by means of a machine worked by hand.

In England the piston propeller is usually set in motion direct by means of a steam-engine. Fig. 311 represents a machine of this description made by Messrs. Clayton, Howlett & Co.

Sometimes the opposite arrangement is adopted, the expression being from bottom upwards, as shown in Fig. 312. In that case the chucks are fixed on vertical rods, which are held immovable at their lower position while the fitting is made, and which are afterwards raised by a counter-poise. This machine was made by Mr. Fawcett.

The working of the preceding apparatus is decidedly intermittent, because, when the cylinder propeller has arrived at

the end of its course, it must be carried back behind and the box must be filled afresh with the body. This takes rather a long time, because the body has to be pressed by manual labour, in such

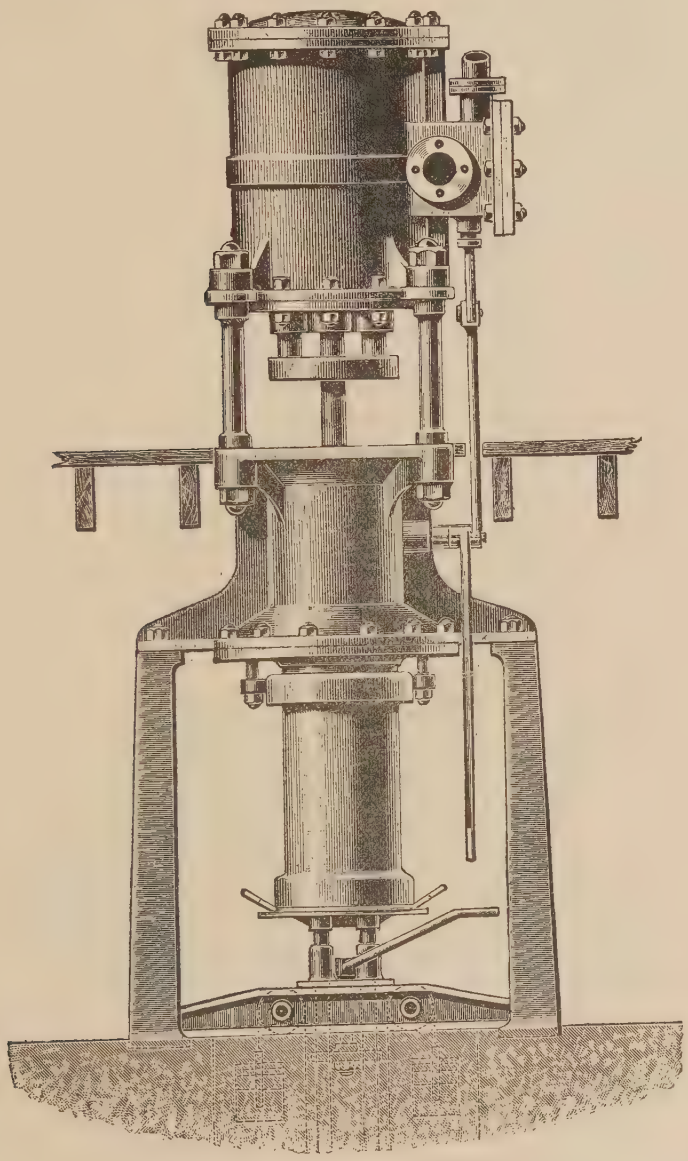


Fig. 311.—Machine for Expressing Pipes.

a way as to prevent, as much as possible, any air remaining in it. This air, in spite of the valves with which the dies of these machines are sometimes provided, will form bubbles in the thickness of the pipes and thus make them unusable.

In France they generally prefer, at least for those with a diameter below 28 ins., presses with roller propellers. Fig. 313 shows an apparatus of this kind made by MM. Boulet & Cie, the working of which is thus continuous, except, of course, for the unavoidable stoppages required for cutting, raising the pipe and remounting the balanced platform. The dies, as well as their nave (bell) and the chuck which is used for the fitting part, are

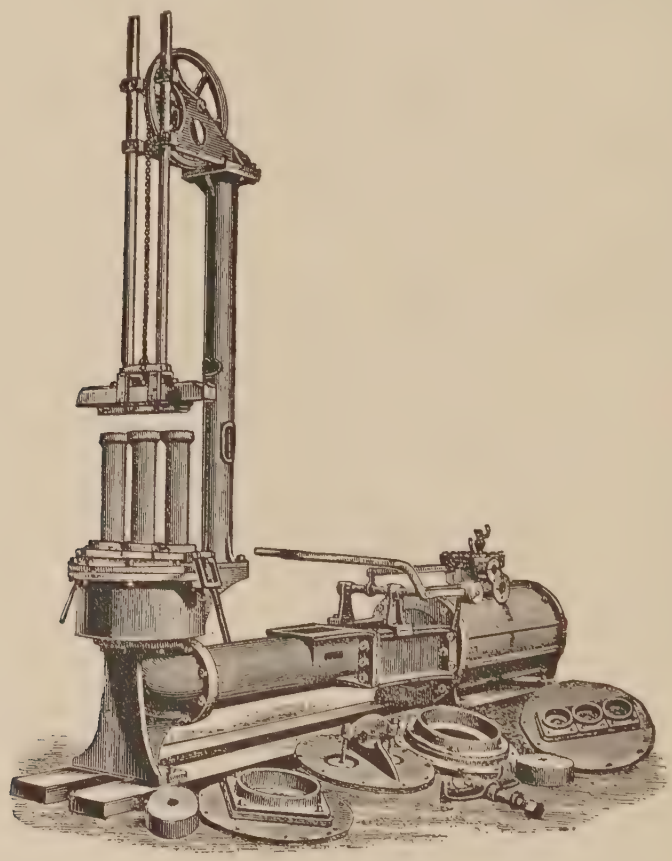


Fig. 312.—Machine for Expressing Pipes.

covered with plaster. The air bubbles are less to be feared, relatively, if they are careful never to let the pressing box become partially empty.

It is wise to use two of these presses, one for small size pipes, two or three of which can be made simultaneously, and the other for large sizes. The production is about fifty pipes of 7·87 ins. diameter an hour.

When the pipes that have been made are sufficiently dried, they are placed on two horizontal cylinders covered with plaster, which have a rotatory motion that they give to the pipes, which allows of the defective parts of the fitting being touched up by hand, and of their being striated so as to increase the adherence of the mortar when it is put on. Then the pipes are placed in drying sheds, the waste heat from the kilns being made use of, or else they are specially heated and ventilated. In some works they are rolled about on plain sheets of iron before they are completely dry, so as to get rid of the elliptical form that may easily occur when unequally dried.

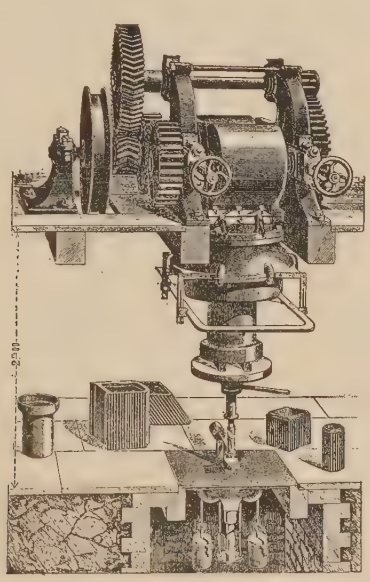


Fig. 313.—Machine for Finishing Pipes.

Elbows, junctions, such as those represented on Fig. 310, are made with the ends of straight pipes that are cut off and joined together by hand.

**279. Burning and Salting.**—The burning is done either in round kilns with down draught, or in semi-continuous kilns or continuous ones with several burning spaces, according to the production. They are heated either by coal or gas. The pipes are placed in bulk, upright, fitting one into the other to a height of 6 ft. 6 ins. to 8 ft. Care must be taken that the inside of them can get the circulation of the gas, in order that

the salting, of which we shall speak, may be done regularly on all sides. Small pipes can be put inside the large ones, but, in spite of this facility, the weight of goods placed in a given volume is small, which considerably increases the cost of burning.

When heated by gas, the kiln already described (Fig. 306, page 678) for burning tiles can be employed. The arrangement shown in Fig. 176 (page 374) can also be used.

When heating by coal is preferred, for small quantities the kiln that will be described further on can be used (Fig. 317, page 694), and for a more important production the semi-continuous kiln shown in Fig. 314. It is composed of a series of burning spaces, the perforated bottom of which communicates, by means of channels, with openings placed along one of the sides of the following chamber. In the same way as in kilns with channels, the air strictly necessary for combustion is brought in under the gratings; the recuperation is only caused by a small proportion of air in excess.

In theory, the heating by flames which entirely descend, as in the types of kilns shown in Figs. 174, 176, 314 and 317, is preferable to heating by flames that are partly ascending, as in the kilns of Figs. 175 and 306, because the maximum temperature is produced at the top of the charge instead of attacking the lower pieces, which, being more loaded, are more liable to get out of shape.

The characteristic operation of burning stoneware pipes is salting, that is to say, the throwing into the kiln, at the time when the highest temperature has been reached, of a certain quantity of sea salt. This volatilises at a temperature slightly above 800° C., but it only decomposes when towards 1,200° C., when in contact with silica. The sodium set at liberty oxidises, forms soda that combines with the silica of the body, and thus causes a superficial vitrification. The chlorine, on its part, decomposes the steam furnished by the combustion and escapes in the form of hydrochloric acid.

For a long time it was thought that the decomposition of the salt was due to the mixture of its vapour, at a high temperature, with the water vapour. This explanation is erroneous:

the salt is decomposed at a high temperature in the presence of

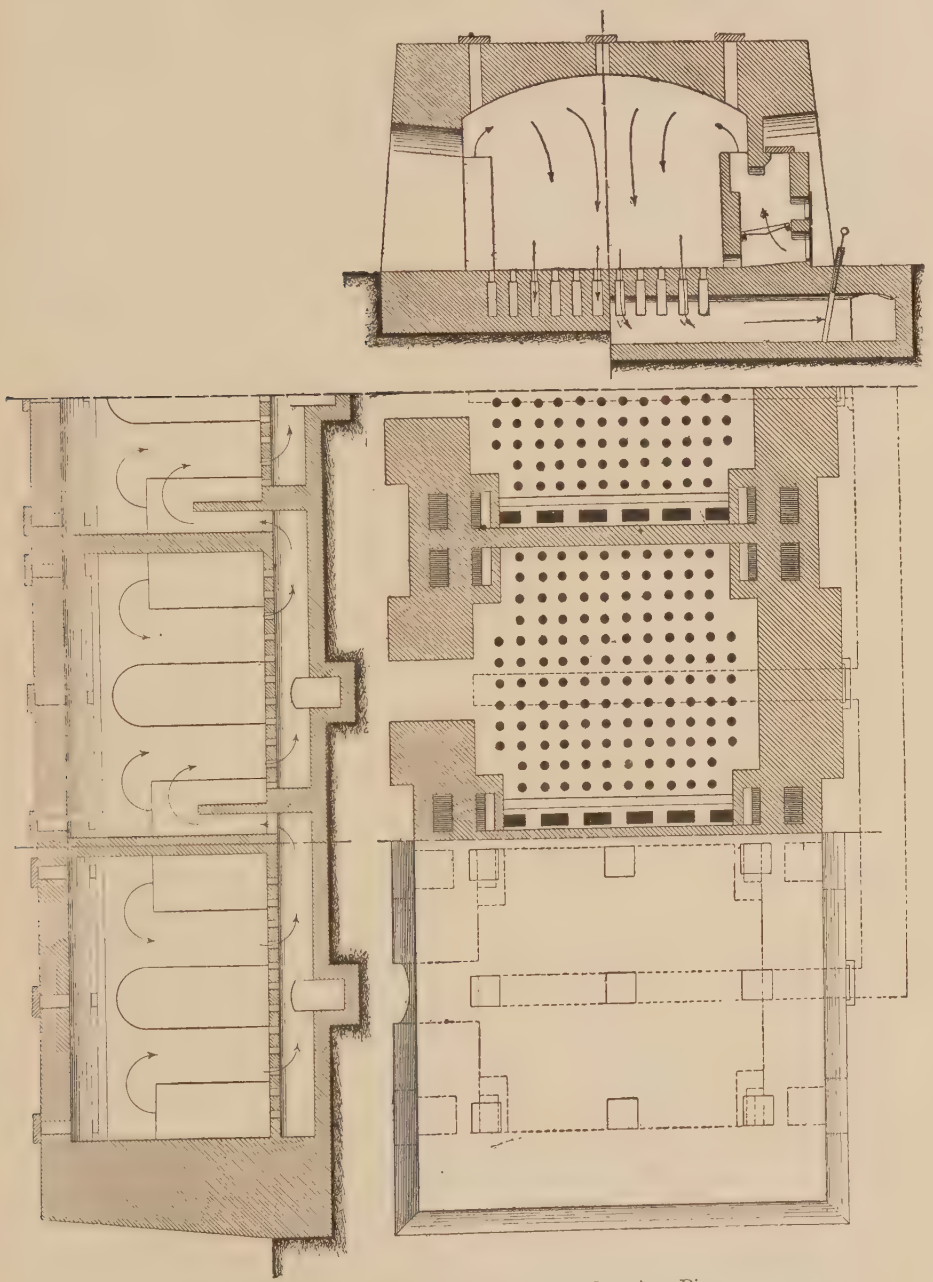


Fig. 314.—Semi-Continuous Kiln for Burning Pipes.

silica; the production of hydrochloric acid is one of the consequences of this dissociation, but is not the cause of it.

This decomposition is better, that is to say, that the glaze is

thicker and more impermeable, the more silica that is contained by the body. Aluminous, or decidedly basic, wares cannot be covered with a saline glaze applied in this way by volatilisation.

The salt is introduced into the kiln by openings arranged in the domes, care being taken that it does not fall directly on to the goods. It produces a decided and rapid lowering of the temperature, because of the considerable amount of heat absorbed by the salt in order to heat, volatilise, and decompose it. This heat has not yet been precisely measured, but it may be reckoned at 800 to 900 units of heat per kilogramme. It is sufficient to lower by 200° to 300° the temperature of the atmosphere of the kiln and of the surface of the goods, therefore the salting ought to be done in two or three operations, from twenty to thirty minutes apart, and the heating increased between. The proportion of salt put in varies from ·625 lb. to 1·25 lb. per cubic foot of the charge.

It is wise while salting to reduce the draught to the minimum that the intense heating will bear, so that the saline vapours should not be too quickly carried off into the chimney. The colour of the pipes naturally depends, as we have seen, on the composition of the body and on the working of the fire during the time of burning which precedes the salting. Yet, it should not be reducing enough to cause a deposit of carbon on the goods, as this deposit would afterwards prevent the contact of the silica and the salt vapour. If the proportion of salt is too great the goods will present, after they have been burnt some time, white deposits, which can be washed off.

The salt acts, not only on the goods, but also on the walls of the kiln, and rapidly destroys them if in building them care has not been taken to employ sufficiently aluminous bricks, that is, bricks in which silica is not found in a free state. Salting was practised for the first time about 1690 in England by the Brothers Flers.

**280. Tests for Pipes.**—The decisions of the Committee on the methods of testing building materials which were given in Art. 231 under the heading *Resistance of Breakage by Internal Pressure* apply especially to stoneware pipes. It is sufficient to add that real stoneware pipes resist considerable pressure, vary-

ing from 5 to 15 atmospheres, or even more, without any breakage taking place during the continuation of the test. When the experiment is well conducted, that is to say, when the joints are well made and do not cause a supplementary strain on the material, the breakage is produced along one of the edges of the pipe. Pipes made of fireclay body are less resisting, and it is seldom that no leakage occurs before the end of the experiment.

The tests are made either on a single end of pipe or on a series of two or three pipes.

### (c) *Sanitary Ware.*

281. For some years, by this name have been designated pottery goods used for certain channels and various domestic purposes. They are distinguished from the preceding ones by a finer body, a more careful preparation; sometimes they are covered with a salt glaze, but more usually with an opaque white glaze.

Fig. 315 shows some of the most usual types.[1]

The preparation of the body is done in the same way as for pipes, but it is always vitrifiable, and with a somewhat fine grain, so as to be able to be glazed. Its plasticity makes it easy to mould the rather complicated shape of the objects that often are wanted, and can only be managed by moulding by hand. For some patterns the ends of drawn pipes can also be used; these are afterwards cut and joined together.

As these wares are generally manufactured in pipeworks, they are burnt in the kilns that have just been described, but those which are to have an enamel of course are not salted.

The enamel used is of the same composition as for feldspathic faience, that is, an alkaline boracic plumbiferous one (Art. 259), rendered opaque, so as to hide the colour of the body, by the addition of a little oxide of tin. Different coloured glazes can also be employed. The vitrification of the enamel is done in muffle kilns. In some cases the glaze is gilded or covered with vitrifiable colours that are fixed by a third baking.

[1] Taken from the Catalogue of the Society for Ceramic and Fireproof Goods at Boulogne-sur-Mer.

Sanitary wares are sometimes also manufactured of faience or of fine stoneware body. In that case, the body being white, naturally, transparent enamels are made use of.

By manufacturing sanitary wares that are impermeable, unchangeable, having, on account of its glaze, a whiteness of irreproachable appearance, pottery has lent an extremely precious aid to the new science of hygiene. These wares, which were invented in England, have for a long time been manufactured

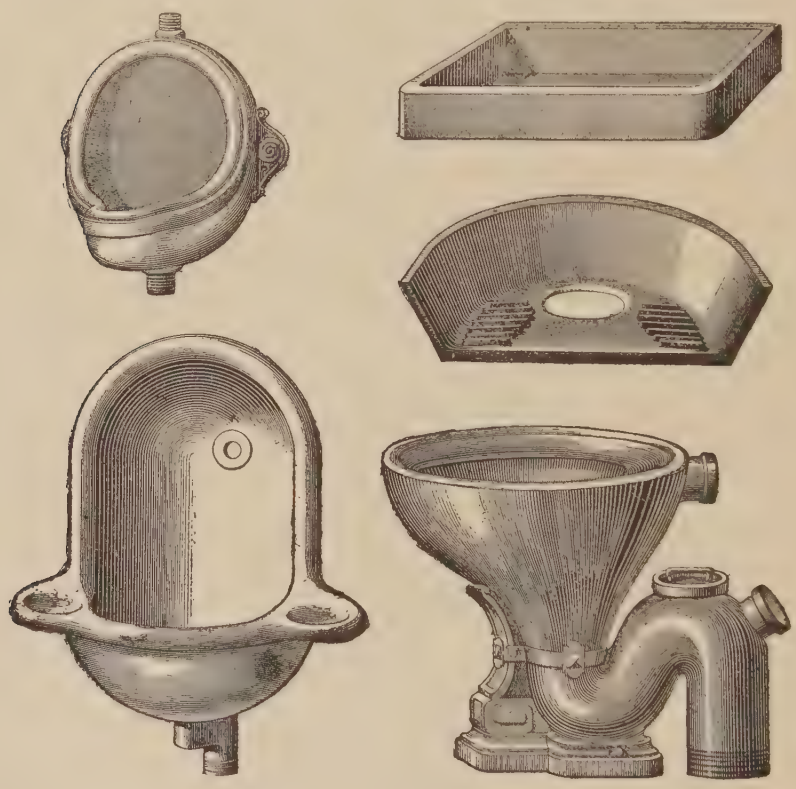


Fig. 315.—Sanitary Pottery.

exclusively in that country. Since then the manufacture of them has extended, and several works, notably in France, send out goods that bear comparison with the best English ware.

### (*d*) *Stoneware for Food Purposes and Chemical Productions.*

**282.** The wares that are included under this heading are mostly those that Brongniart meant by the name of common

stoneware. The manufacture of pots intended to hold liquids was the first, and, for a long time, the only use for stoneware. Then, towards the end of the eighteenth century, they began to be used for making chemicals, and for this purpose have reached a high point of perfection. The principal merit belongs to Messrs. Doulton & Co., who thus rendered an inestimable service to this industry.

Fig. 316 represents, by way of general examples, some of the goods in common use.

The body employed for the manufacture of these wares is almost always a fairly pure vitrifiable clay, so that it does not

Fig. 316.—Stoneware for Preparing Food and Chemicals.

need to be washed. It is carefully prepared and principally made on the wheel. Some pieces, however, on account of their shape have to be made in a mould. Lastly, it is only rarely that expression can be utilised to make, for example, the cylindrical part of pots or bottles, the bottoms and upper brims, or the neck, being joined on afterwards.

For a long time they were burnt in horizontal kilns with a single fireplace (Art. 166). We have already given the reasons for condemning this kind of kiln; also, it is better to replace them by round kilns with descending flames. Fig. 317 shows a kiln of this description, which can also be used for

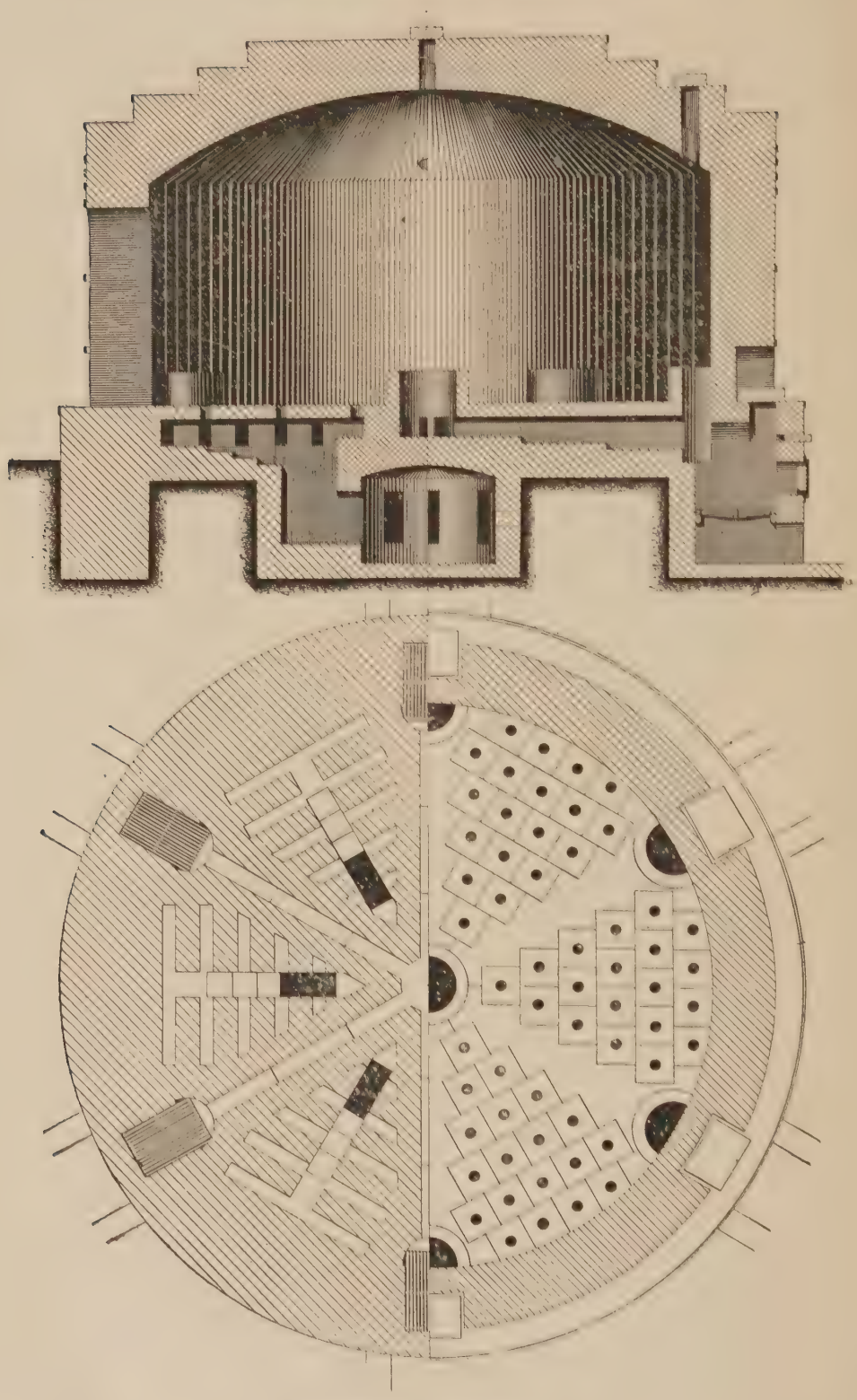


Fig. 317.—Kiln for Stoneware.

burning pipes and other stoneware goods when the production is not sufficient to allow of burning them in a continuous kiln. These kilns can be as much as 23 ft. to 26 ft. in diameter, the height not being more than 6½ ft. to 10 ft., because, being charged in bulk, a greater height would cause the lower rows to be crushed when they soften. In the engraving the passing off of the gas is shown as being accomplished through a rather large number of small openings. This arrangement is specially used in burning pipes; for other stoneware a smaller number of larger openings can be employed. The openings shown in the dome are used for salting, the salt being thus thrown on to the fireplaces, so as not to touch the ware.

This species of stoneware is generally rough or covered with a salt glaze, when it is desirable to make them absolutely impermeable. This glaze can be made a deep brown colour, by using the method indicated for making tiles black immediately after they have been salted. Then there is formed a deposit of carbon that becomes incorporated in the glaze while still pasty. This trick needs a certain amount of skill. The salt glaze is sometimes replaced by a cheap glaze, applied by immersion, with a brush, or by powdering, on the unburnt body. Naturally, this glaze must be vitrified at the temperature that suffices to burn the body; it cannot then be plumbiferous. As the alkaline-calcareous glazes, the only ones that can be used, are somewhat costly, they are sometimes replaced by the slag of the blast furnace, or by a mixture of cinders, lime and sand.

Stoneware for preparing food or for chemical purposes is manufactured in England in large factories, while in France and Germany it is the specialty of a rather large number of small potteries, which are grouped together in the neighbourhood of the beds of vitrifiable clay; the quality of these goods depends upon that of the clay.

### (*e*) *Architectural Stoneware.*

**283.** In this name we include those stonewares which have begun to be used in the construction and decoration of buildings, inasmuch as they are neither pipes nor tiles. Except some ancient

uses in China, this way of using them is quite recent, but we may certainly predict a brilliant future for them.

The impermeability and hardness of stoneware give it a considerable advantage over terra cotta. Unfortunately, this advantage is usually largely compensated for by the difficulties of manufacturing it, and especially by the tendency of stoneware to get out of shape when it is burnt. Up to the present time they have not been able to succeed in an ordinary way and as an industry except with objects that are little likely to get out of shape. Besides, on principle, we ought not purely and simply to try to imitate terra cotta, but also to create special patterns for stoneware. Thus, for example, fitting tiles, easily manufactured in terra cotta, have such a tendency to warp when made in stoneware, that, at least when being sorted, there is such a large proportion thrown out that the advantage of fitting them together becomes imaginary.

It is advisable, while on this subject, to again call attention to what has been said about the composition of paving tiles. The fluxes, if they form part of the vitrifiable clay, or, still more, if they are added in the shape of limestone, cause the softening and loss of shape of the body at the same time as its vitrification. This defect can only be remedied by the addition of silica, the proportion of which is limited by the necessity of keeping the body sufficiently plastic. That no longer applies if alkaline fluxes in the shape of silicates are added to a relatively fireproof clay. Unfortunately, the rocks that are sufficiently alkaline are very rare or costly to prepare, but they can be replaced by scoria, slag or broken glass. It seems to us that in this direction it is best to commence, if it is desirable to manufacture stoneware goods that are sufficiently resistant while being burnt, by borrowing, at least partially, the terra cotta shapes.

Architectural stoneware can be dull, or covered with a glaze. For some effects this can be a salt glaze, but, as a general rule, it is better to have recourse to more fusible glazes, fixed by a second burning at a lower temperature. Theoretically, opaque enamels do not for this purpose look nice. It is better, in spite of the colour of the body, to make

use of transparent or coloured enamels, and even varnishes. The latter allow of very beautiful decorative effects being obtained, which harmonise better with the architectural decoration than the hard tones of the opaque enamels.

### (*f*) *Vases, Statues and other Decorative Objects.*

**284.** We have seen in the history of ceramics that the Chinese used stoneware from very ancient times for the manufacture of vases and other ornamental objects, and that this manufacture began in Europe, in the fifteenth century, in the Duchy of Limburg. Since that time it has followed the fluctuations of fashion, disappearing completely, then reappearing again, without, however, at any time being of much importance. The first ware obtained by Böttger, which he called by the name of red porcelain, belongs to this class of goods. In the last few years it seems that the favour enjoyed by stoneware would cause the development of this kind of ware. The very meritorious effort of M. Emile Muller will have contributed largely to it.

For these objects, which are rather expensive, bodies of different colours can be employed, as we said when speaking of tiles, and the care with which they must be saggered allow of the using of vitrifiable clays without bad effects.

The great advantage of this stoneware, as compared with porcelain or even calcareous or feldspathic faience, is the plasticity of the body, which allows it to be modelled by hand without employing moulds. As it lends itself to the same process as ordinary modelling clay, it makes the creation of original works of art possible, that possess, when burnt, the same qualities of resistance and indestructibility as stone or bronze, without requiring any retouching, or the troublesome working of sculpture.

We must also observe that the close grain of the body, as well as its colour, give a more agreeable appearance to the object when modelled in stoneware than when done in terra cotta.

If we consider the decorative shaping should be the principal method of ornamenting stoneware, it does not follow that

colour must not be used also; on the contrary, enamels blend very well with the more or less coloured background of the body, as they have not the hard look that other wares have when only partially enamelled. All kinds of glazes and all the methods of decoration can be employed; yet gilding, which is so suitable for the white body of porcelain when used with stoneware, does not generally yield satisfactory results.

### 2. *Fine Stoneware.*

**285.** Fine stoneware was invented in England; in other countries it has only been imitated by a small number of potters. It is somewhat remarkable that, while among other European nations enamelled faience, stoneware properly so called, and hard porcelain represent very distinct types with decidedly marked characteristics; in England feldspathic faience, fine stoneware, and phosphated porcelain are the wares that are most similar to one another, manufactured by the same methods, burnt at about the same temperature, and are often very difficult or even impossible to be distinguished from each other.

The following are some examples of the English compositions. We shall see that the raw materials are the same as those used for feldspathic faience, but the proportion of pegmatite is increased and that of the flint diminished:—

| | | | | | |
|---|---|---|---|---|---|
| Blue clay . . . | 10 | 25 | 29 | 45 | 28·5 |
| Kaolin . . . | 15 | 12·5 | 14 | 15 | — |
| Flint . . . | 20 | 12·5 | — | — | — |
| Pegmatite . . . | 55 | 50 | 57 | 40 | 71·5 |

The greater the amount of kaolin, the whiter the body; with clay alone it is yellowish.

The chemical composition of the white bodies is approximately the following:—

| | |
|---|---|
| Silica . . . . . | 70 to 75 |
| Alumina . . . . . | 20 ,, 25 |
| Oxide of iron . . . . . | traces |
| Lime . . . . . | 0·5 to 1 |
| Alkalies . . . . . | 3 ,, 5 |

Heavy spar is sometimes added in large proportion (as much as 50 per cent.), the amount of pegmatite being lessened in that case.

The body is coloured by the means already indicated: ½ to 1 per cent. of oxide of cobalt gives blue, the same proportion of oxide of chromium green; 7 to 8 per cent. of a mixture of oxide of iron and oxide of manganese makes brown, etc. For the black called basaltic, the pegmatite is replaced by a large proportion of red ochre and oxide of manganese. The following is an example of one of these bodies:—

| | |
|---|---|
| Blue clay . . . . . | 43 |
| Calcined ochre . . . . . | 43 |
| Oxide of manganese . . . . . | 14 |

The preparation of the body and the moulding are done by the same methods as those described for feldspathic faience. It is also burnt in the same way, and with much the same temperature.

Fine stoneware is frequently dull. Sometimes the surface is vitrified by covering the inside of the saggers with a coating composed of sea salt, potash and oxide of lead, or of sea salt, saltpetre and white lead. The lead volatilises, probably in the form of a chloride, which glazes the surface of the ware.

The glazes are almost always alkaline boracic plumbiferous, like those for feldspathic faience; sometimes the oxide of lead and a part of the pegmatite is replaced by heavy spar.

# CHAPTER XIII.

## PORCELAIN.

SUMMARY.—Classification.

SEC. 1. *Hard Porcelain:* (*a*) *Porcelain for Table Ware and for Decoration:* Composition of the Body and the Glaze—Preparation of the Body—Moulding—Drying, Warming and Application of the Glaze—Burning—Saggering—Decoration—General Arrangements of Porcelain Works. (*b*) *Porcelain for the Fire.* (*c*) *Porcelain for Electrical Conduits.* (*d*) *Porcelain for Mechanical Purposes.* (*e*) *Architectural Porcelain.* (*f*) *Dull Porcelain, called Biscuit Porcelain.*

SEC. 2. *Soft Phosphated Porcelain*, called English Porcelain.

SEC. 3. *Soft Vitreous Porcelain*, called French Porcelain.

SEC. 4. *Soft Vitreous Porcelain*, called New Sèvres Porcelain.

SEC. 5. *Argillaceous Soft Porcelain*, called Seger's Porcelain.

SEC. 6. *Dull Soft Porcelain*, called Parian Porcelain.

SEC. 7. *Dull Feldspathic Soft Porcelain.*

**286. Classification.**—Porcelains[1] are impermeable, translucid wares with a white body, or else a coloured one, but only for a decorative purpose. Their impermeability distinguishes them from the terra cottas and faiences, and their being translucid makes them differ from stoneware.

We have seen, when speaking of these latter wares, that impermeability is only relative, it is the same with translucidity. In order to define precisely this property of matter, it is necessary in fact to specify the thickness of the body and the intensity of the source of light. When only slightly thick, the little coloured stoneware and some feldspathic faience that is rich in flux possess in fact a relative lucidity. On the other hand, no

[1] Before the sixteenth century this word was used to denote the objects manufactured with the mother of pearl from the shell called porcelain. After that time it was used, from the similarity of appearance, to indicate Chinese ware. French *porcelaine*, Ancient French, *pourcelaine*, Italian *porcellena*, from the Latin *porca*, the vulva of the sow.

matter what the kind of porcelain, it becomes opaque when the thickness of the body is increased to a sufficient extent.

Up to the present time there is in existence no precise rule for determining at what time opacity ceases and translucidity begins. It is a question of appreciation, in which the competent potter takes account of all the other physical properties of the body and the glaze, as well as of the methods of manufacture which this examination may reveal to him. We have not said this in order to contest the value of the classification adopted by all potters, but in order to point out the difficulties into which one is sometimes landed while applying it.

Hard porcelain is distinguished from tender porcelain ; these two adjectives should be taken first in the sense of their resistance to heat, and afterwards of the effective mechanical hardness of the glaze.

*Hard porcelain* has a silicious body made of kaolin, with the addition of alkaline fluxes or partly calcareous ones. It is almost always covered with a glaze, the vitrification of which takes place at the same time as the burning of the body, at a temperature varying from 1,300° to 1,400° C. The glaze cannot be scratched with steel.

These porcelains form a well-defined group, which is fairly easily distinguished from all other wares. From the point of view of use, the six following varieties can be principally, if not exclusively, distinguished from one another:—

(*a*) *Porcelain for table ware and for decoration,* used, as the name indicates, for the service of the table, and as decorative objects.

(*b*) *Porcelain for the fire*, that is to say, intended to be submitted to heat.

(*c*) *Porcelain for electrical conduits.*

(*d*) *Porcelain for mechanical purposes.*

(*e*) *Architectural porcelain.*

(*f*) *Dull porcelain, called biscuit porcelain.*

*Tender porcelain*, on the contrary, includes a certain number of kinds of ware, which are very different from nearly all points of view, having scarcely anything in common except that the degree at which they are burned is lower than that of the hard porcelains, and, when they are not dull, the less hardness of their glaze.

## 1. *Hard Porcelain.*

### (a) *Porcelain for Table Ware and for Decoration.*

**287. Composition of the Body.**—The body for hard porcelain is a mixture of kaolin, silica, and alkaline fluxes. Sometimes a part of the alkalies is replaced by lime. It is only in very rare cases that it is necessary to insist that magnesite or talc has been partially substituted for the kaolin.

The qualities the body for hard porcelain should possess are :—

1. Sufficient plasticity for it to be suitable for moulding.

2. A sufficiently high temperature for burning it, so as to allow of the employment of a very hard, and consequently of a slightly fusible glaze.

3. As great a translucidity as possible.

4. Colouring of a slightly bluish white.

The hydrosilicate of alumina in the form of clay properly so called, which serves as a basis for all the bodies already described, can no longer be used. It would make bodies that were too fusible or too opaque, and which in any case would not be of the required whiteness. On the other hand, in the form of kaolin, the hydrosilicate of alumina is more fireproof, and makes the bodies more translucid and whiter.

The kaolins, even those that are sufficiently pure to be used for the manufacture of porcelain, are very different in composition and properties. In order to decide upon their value, the constituents of them must first be decided, as said in Art. 49, by trying them with sulphuric acid. The part dissolved contains hydrosilicate of alumina, and, according to M. Vogt's works, some impalpable mica, while the residuum is formed of quartz and feldspar. After having made the precise analysis of these two parts, the dissolved alkalies may be ascribed to the mica, by regarding it as having the composition of muscovite,

$$6SiO^2, 3Al^2O^3, K^2O, 2H^2O,$$

and it is agreed that the insoluble alkalies are in the form of orthose feldspar,

$$6SiO^2, Al^2O^3, K^2O,$$

soda being reckoned as potash in valuing the relation of the

equivalents. Thus the proportions of the mixture of hydrosilicate of alumina, quartz, feldspar, and mica are obtained which make up kaolin.

In spite of this somewhat exact definition, it is necessary to make a practical experiment in order to find out its plasticity. The dimensions, and probably the shape, of the grains of hydrosilicate of alumina are in fact more variable in kaolin than in clays properly so called. So that the less plasticity it has, as in the Cornish kaolins, the nearer it resembles that of the plastic clays, as in the kaolins from China and Japan.

It is only after having made this double experiment that the quantity of opening materials and fluxes which it is necessary to add can be determined, in order to try and get a body similar to what was suggested as a type. The opening materials are quartz, quartzeous sand, or biscuit porcelain; the fluxes are feldspar, pegmatite, or carbonate of lime. It frequently happens that a single kaolin, especially when it is an open one, cannot give the needful composition, thus two, or even three, are obliged to be mixed together.

The following are the results of some rather ancient analyses of different bodies of burnt porcelains :—

| | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Potash. | Soda. |
|---|---|---|---|---|---|---|---|
| Sèvres, body for table ware | 58·0 | 34·5 | — | 4·5 | — | 3·0 | — |
| ,, ,, sculpture | 64·2 | 30·0 | — | 2·9 | — | 2·8 | — |
| Limoges | 70·2 | 24·0 | 0·7 | 0·7 | 0·1 | 4·3 | — |
| Meissen | 58·5 | 35·1 | 0·8 | 0·3 | 0·6 | 5·0 | — |
| ,, | 60·0 | 35·5 | — | 0·6 | — | 2·3 | 1·6 |
| Berlin | 64·3 | 29·0 | 0·6 | 0·3 | ·5 | 3·6 | — |
| Vienna | 59·6 | 34·2 | 0·8 | 1·7 | 1·4 | 2·0 | — |
| Nymphenburg | 72·8 | 18·4 | 2·5 | 3·3 | 0·3 | 0·6 | 1·5 |
| Schlaggenwalde (Bohemia) | 71·5 | 23·4 | — | 0·1 | 0·1 | 3·1 | 1·0 |
| China | 69·0 | 23·6 | 1·2 | 0·3 | — | 3·3 | 2·9 |
| ,, | 69·0 | 21·3 | 3·4 | 1·1 | — | 3·4 | 1·8 |
| ,, | 70·0 | 22·2 | 1·3 | 0·8 | — | 3·6 | 2·7 |
| ,, | 73·3 | 19·3 | 2·0 | 0·6 | — | 2·5 | 2·5 |
| Japan | 70·7 | 21·8 | 2·0 | 0·7 | tr. | 3·2 | 2·4 |

The following table gives the more recent analyses made by Seger on the unburnt bodies :—

| | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Potash. | Soda. | Water. | Carbonic Acid. |
|---|---|---|---|---|---|---|---|---|---|
| Sèvres, body for table ware | 52·94 | 28·91 | 0·48 | 3·99 | 0·17 | 1·70 | 0·68 | 9·12 | 2·48 |
| Limoges, I. Pouyat, superfine body . . . | 64·28 | 23·49 | 0·87 | 1·77 | tr. | 1·11 | 3·07 | 5·48 | 0·69 |
| Limoges, I. Pouyat, ordinary body . . . | 64·52 | 22·07 | 0·97 | 2·10 | tr. | 1·35 | 3·13 | 5·60 | 0·57 |
| Limoges, L. Sazerat, superfine body . . . | 64·32 | 23·64 | 0·83 | 0·86 | tr. | 2·66 | 1·82 | 5·98 | — |
| Limoges, L. Sazerat, ordinary body . . . | 60·42 | 26·47 | 0·52 | 1·37 | — | 2·75 | 1·60 | 7·19 | — |
| Limoges, L. Sazerat, heavy porcelain . . . | 60·53 | 26·37 | 0·75 | 0·69 | tr. | 2·95 | 1·44 | 6·39 | — |
| Limoges, Guérin et Cie, superfine body . . | 65·61 | 23·07 | 0·65 | 0·80 | tr. | 2·94 | 2·72 | 4·50 | — |
| Limoges, Guérin et Cie, ordinary body . . | 66·00 | 22·59 | 0·36 | 1·68 | — | 2·71 | 1·80 | 5·59 | — |
| Limoges, Guérin et Cie, body for figures . . | 65·79 | 23·51 | 0·31 | 1·59 | — | 2·01 | 1·73 | 5·89 | — |
| Vierzon, superfine body . | 66·97 | 20·92 | 0·64 | 2·06 | tr. | 2·75 | 0·41 | 5·43 | — |
| ,, heavy porcelain . | 63·48 | 25·00 | 0·51 | 1·06 | — | 2·26 | 1·19 | 6·76 | — |
| Hal (Belgium), heavy porcelain . . . . | 63·95 | 25·59 | 0·69 | tr. | 0·54 | 2·07 | 0·98 | 6·62 | — |
| Berlin, body for table ware | 63·07 | 24·67 | 0·59 | — | 0·40 | 4·25 | (1) | 7·00 | — |
| Carlsbad . . . . . | 66·78 | 22·70 | 0·55 | 0·97 | tr. | 1·07 | 1·51 | 6·07 | 0·55 |
| ,, . . . . . | 65·17 | 23·63 | 0·51 | 1·09 | tr. | 2·92 | 0·90 | 5·98 | 0·70 |
| Japan . . . . . | 74·53 | 16·09 | 1·03 | 0·06 | 0·25 | 4·37 | 1·19 | 2·83 | — |
| ,, . . . . . | 71·31 | 19·74 | 0·73 | 0·17 | — | 4·04 | 0·10 | 4·01 | — |
| ,, . . . . . | 71·60 | 18·71 | 1·19 | tr. | — | 4·16 | 0·18 | 4·68 | — |

(1) The Soda is reckoned with the Potash.

By comparing the foregoing numbers we can recognise, as Seger does, four types of porcelain :—

1. Sèvres porcelain.

2. Heavy French porcelain, Hal porcelain, Berlin and Carlsbad porcelains.

3. French porcelain of superfine quality.

4. Japanese porcelain.

The respective compositions of these four types group themselves more clearly if the medium ones are taken, by reckoning according to the burnt bodies. The following figures give this calculation :—

| | Silica. | Alumina. | Oxide of Iron. | Lime. | Potash. | Soda. |
|---|---|---|---|---|---|---|
| Type 1 . . . . | 59·6 | 32·6 | 0·6 | 4·5 | 2·0 | 0·7 |
| ,, 2 . . . . | 67·8 | 26·7 | 0·7 | 0·8 | 2·9 | 1·1 |
| ,, 3 . . . . | 69·1 | 24·0 | 0·7 | 1·6 | 2·3 | 2·3 |
| ,, 4 . . . . | 75·5 | 19·0 | 1·0 | — | 4·3 | 0·6 |

By comparing these results with the figures contained in the first table of analyses, we see that this division into four types is fairly well confirmed. In order to facilitate the comparison, we may represent the composition by the symbol

$$mRO, R^2O^3, nSiO^2$$

in which $mRO$ represents the fluxes, lime, magnesia, potash, and soda, $R^2O^3$ the alumina and peroxide of iron, taken as united together, and $nSiO^2$ the proportion of silica.

Under these conditions the first type, that is the Sèvrès, according to Seger's analysis, would correspond to the formula

$$0{\cdot}35RO, R^2O^3, 3{\cdot}0SiO^2.$$

Looking at the other analyses of the Sèvres body, and including in the same class the bodies from Meissen and Vienna, we see that we can give to these porcelains the general formula

$$0{\cdot}30 \text{ to } 0{\cdot}35RO, R^2O^3, 2{\cdot}8 \text{ to } 3{\cdot}5SiO^2.$$

The second type, including some heavy bodies from Limoges and Vierzon, the porcelains from Hal, Berlin, and Carlsbad, would have as a formula

$$0{\cdot}20 \text{ to } 0{\cdot}30RO, R^2O^3, 4{\cdot}2 \text{ to } 4{\cdot}8SiO^2.$$

The third type, which corresponds to the bodies of superfine quality from Limoges, is represented by

$$0{\cdot}40 \text{ to } 0{\cdot}45RO, R^2O^3, 4{\cdot}8 \text{ to } 5{\cdot}3SiO^2.$$

Lastly, in the fourth or Oriental type, the Chinese porcelains would have the formula

$$0{\cdot}40 \text{ to } 0{\cdot}45RO, R^2O^3, 5{\cdot}5 \text{ to } 6{\cdot}0SiO^2,$$

and the Japanese

$$0{\cdot}30 \text{ to } 0{\cdot}40RO, R^2O^3, 6{\cdot}2 \text{ to } 7{\cdot}4SiO^2.$$

We know that at the high temperature at which porcelain is burnt the silica becomes a fusible element, so that the different types of the foregoing bodies are classed in the order of their fusibility. According to M. Vogt, the Sèvres body, which is the most refractory, is burnt at Seger's test No. 15 (Art. 180), and the Chinese bodies at test No. 12.

By applying to the four types of bodies defined by Seger's analyses what has already been said on the subject of the constituents of the bodies, we can make out the following table,

which rests partly on hypotheses, but nevertheless is interesting:—

| | Carbonate of Lime. | Soluble Part in the Sulphuric Acid. | | Insoluble Part in the Sulphuric Acid. | |
|---|---|---|---|---|---|
| | | Hydrosilicate of Alumina. | Impalpable Mica. | Quartz. | Feldspar. |
| Type 1 . . . | 6·47 | 59·80 | 6·57 | 12·05 | 15·11 |
| ,, 2 . . . | — | 48·89 | 6·28 | 24·34 | 20·49 |
| ,, 3 . . . | — | 40·99 | 4·13 | 23·87 | 31·01 |
| ,, 4 . . . | — | 33·13 | 9·56 | 42·60 | 14·71 |

Some bodies of the second and third types also contain a little carbonate of lime added directly, but in the others the small amount of lime comes from the feldspar.

As to the plasticity, we see that the European kaolins would contain scarcely more than a tenth part of very fine mica, while in the Japanese this proportion is as high as 20 per cent. or 25 per cent. M. Vogt proved by experiment that the impalpable mica possesses a plasticity analogous to that of the clay properly so called. This great proportion explains in some measure the remarkable plasticity of the Oriental bodies. We say in some measure, because we must admit besides that the hydrosilicate of alumina in the kaolins from China and Japan is more plastic than that contained in the European kaolins. We have sometimes attempted to make the European bodies as plastic as the Oriental ones by adding to them a certain proportion of white plastic clay. The desired result has thus been attained, but at the expense of the whiteness and translucidity of them.

Those are the conclusions and theoretical considerations which up to the present time the science of ceramics has ascertained as to the composition of the body for porcelain. Doubtless they will not to any extent replace practical tests, which besides are indispensable in all branches of pottery; but they help us to arrive more quickly, and in a more reasonable way, at the object which we aim at.

The raw materials used in France are principally the feldspathic kaolin from Saint-Yrieix, with the addition of a quartzeous stone which is found in the same beds, and a little cement

obtained by powdering biscuit porcelain. In some cases a little carbonate of lime is added, which should be as pure as possible. In Germany and Austria, where the kaolins contain very little feldspar, a direct mixture of kaolin, feldspar and quartz has to be made.

**288. Composition of the Glaze.**—The glazes employed for hard porcelain are silicates of alumina and other bases, principally lime and alkalies. According as the alkaline-earthy bases or alkalies are in preponderating proportion, the glaze is called calcareous or alkaline (that is to say feldspathic).

The following table shows the chemical composition of some of the glazes:—

| | Silica. | Alumina. | Oxide of Iron. | Lime. | Magnesia. | Potash. | Soda. | Loss in the Fire and Sundry. |
|---|---|---|---|---|---|---|---|---|
| Pegmatite used at Sèvres . | 70·64 | 16·87 | 0·73 | 1·31 | 0·20 | 4·22 | 4·97 | 0·34 |
| Pegmatite used at Limoges . | 76·11 | 14·61 | 0·66 | 1·44 | 0·42 | 2·99 | 3·03 | 1·23 |
| ,, ,, | 75·99 | 14·80 | 0·37 | 1·09 | 0·36 | 4·31 | 3·49 | 0·65 |
| Glaze used at Berlin . . | 73·24 | 13·97 | 0·31 | 2·57 | 0·51 | 4·81 | 1·71 | 3·83 |
| Japanese Glaze . . . | 61·97 | 12·92 | 0·39 | 9·59 | tr. | 4·17 | 1·12 | 10·21 (1) |
| ,, ,, . . . | 64·96 | 12·74 | 0·80 | 8·78 | tr. | 1·95 | 2·30 | 9·35 (2) |
| Chinese sea green glaze . | 64·80 | 14·33 | 1·39 | 10·09 | 1·55 | 5·61 | 0·81 | 1·39 (3) |

[1] 0·30 of phosphoric acid is included in it.

[2] 0·16 of phosphoric acid is included in it.

[3] Titanic acid. The first analysis is by M. Vogt, the other six by Seger.

The first four glazes are alkaline glazes, the last three calcareous ones. They may be represented by the following formulas, in which RO indicates the fluxes, $R^2O^3$ the alumina and the peroxide of iron:—

| | |
|---|---|
| Pegmatite used at Sèvres . . | $1{\cdot}0RO,\ 1{\cdot}07R^2O^3,\ 7{\cdot}45SiO^2$ |
| ,, ,, Limoges . . | $1{\cdot}0RO,\ 1{\cdot}00R^2O^3,\ 8{\cdot}91SiO^2$ |
| ,, ,, ,, . . | $1{\cdot}0RO,\ 1{\cdot}24R^2O^3,\ 10{\cdot}84SiO^2$ |
| Glaze used at Berlin . . . | $1{\cdot}0RO,\ 1{\cdot}12R^2O^3,\ 9{\cdot}58SiO^2$ |
| ,, Japanese . . . . | $1{\cdot}0RO,\ 0{\cdot}55R^2O^3,\ 4{\cdot}42SiO^2$ |
| ,, ,, . . . . | $1{\cdot}0RO,\ 0{\cdot}59R^2O^3,\ 5{\cdot}04SiO^2$ |
| ,, Chinese . . . . | $1{\cdot}0RO,\ 0{\cdot}52R^2O^3,\ 3{\cdot}82SiO^2$ |

These formulas are set out (so as to allow of comparison), like those that were given for other glazes, by taking the proportion of the fluxes at unit; but, considering the part played by the alumina in these glazes, it is better to take that as the unit instead. Then they come out as follows:—

| | |
|---|---|
| Pegmatite used at Sèvres . . | $0{\cdot}93RO, 1{\cdot}0R^2O^3, 6{\cdot}96SiO^2$ |
| " " Limoges . . | $0{\cdot}81RO, 1{\cdot}0R^2O^3, 8{\cdot}74SiO^2$ |
| " " " . . | $0{\cdot}89RO, 1{\cdot}0R^2O^3, 8{\cdot}55SiO^2$ |
| Glaze used at Berlin . . . | $1{\cdot}00RO, 1{\cdot}0R^2O^3, 8{\cdot}91SiO^2$ |
| " Japanese . . . . | $1{\cdot}82RO, 1{\cdot}0R^2O^3, 8{\cdot}04SiO^2$ |
| " " . . . . | $1{\cdot}69RO, 1{\cdot}0R^2O^3, 8{\cdot}54SiO^2$ |
| " Chinese . . . . | $1{\cdot}92RO, 1{\cdot}0R^2O^3, 7{\cdot}35SiO^2$ |

We see that the relative proportion of silica and alumina varies little, but that, on the other hand, there is double the amount of fluxes in the Oriental glazes, which accounts for their greater fusibility.

In France, the pegmatite from Saint-Yrieix is almost exclusively used as a glaze, either more or less decomposed, and in that state it is a mixture of feldspar, quartz and kaolin. Its fusibility can be regulated by the addition of a certain quantity of quartz.

In Germany and Austria the glaze is artificially composed of a mixture of these three substances. In those countries for a long time, and even still partially, calcareous glazes were used, in which the lime is introduced either in the form of a carbonate of lime, or else as a burnt sulphate of lime. The following, according to Prössel, are some examples of these compositions:—

| | | | | | |
|---|---|---|---|---|---|
| Quartz . . . . . | 34·5 | 32·0 | 27·0 | 50·0 | 44·0 |
| Kaolin . . . . . | 9·5 | 7·0 | 8·0 | 37·5 | 30·0 |
| Feldspar . . . . . | 32·5 | 37·0 | 32·0 | — | — |
| Carbonate of lime . . . | 12·0 | 11·0 | 16·5 | 12·5 | — |
| Sulphate of lime . . . | — | — | — | — | 13·5 |
| Cement of biscuit porcelain . | 11·5 | 13·0 | 16·5 | — | 12·5 |

In the East the glaze seems to be composed of a stone similar to pegmatite, finely powdered and diluted in milk of lime.

In a general way the calcareous glazes are more transparent and penetrate into the body better, the alkaline glazes are more milky and need to be applied in a thicker layer. But, as these latter give a more velvety and agreeable look to the porcelain, they are generally preferred. The burning of the body and the glaze is done simultaneously, therefore, naturally, there must be a complete agreement between the temperature for vitrifying the body and that for burning the glaze. The foregoing analyses show the limits within which the respective proportions of alumina, silica and fluxes can be varied to attain this end.

**289. Preparation of the Body.**—The bodies are always pre-

pared by the moist method. The kaolin is first sorted and washed, the quartz and feldspathic rocks are also sorted, then powdered. By referring to what was said in Art. 91, we see that the body may be prepared by two methods. In the first the measuring is done when the materials are dry, afterwards being diluted and ground together in water, while in the second the measuring takes place in a liquid state, the raw materials being first diluted and ground separately.

The first method is the one used at Limoges; the second, an imitation of the manufacture of feldspathic faience, is the one most used in Germany and Austria. Whatever the method of grinding and measuring, the liquid body is afterwards sifted, submitted to an electrical purifying, if necessary, and lastly made firm in filter presses. It is then in the form of rather moist cakes, which, when the bodies are prepared in the same works as the manufacture, properly so called, of the porcelain, are placed in cellars, where they are kept for a longer or shorter time before being used for moulding. In some cases the bodies are prepared in special factories, which send out the cakes in a moist state, or else after having first dried them in the open air.

In both cases, before beginning moulding, the body is put into a kneading machine, adding to it if necessary the needful quantity of water; then it is again kneaded, chiefly to get rid of any air bubbles it may contain. These operations were described in Art. 91.

**290. Moulding.**—The moulding of porcelain presents much greater difficulties than that of any other ware. First, the body, which is nearly always a very short one, lends itself very badly to all the methods of moulding, which are based on the use of a plastic material. Then, owing to the ware being softened in the firing, and having consequently a tendency to fall in under its own weight, it is necessary to give it a variable thickness, strengthening the parts on which they will rest in charging and diminishing the other parts. Lastly, on account of the considerable shrinkage which takes place at vitrification, porcelain also has a tendency to get out of shape if the body of which it is moulded is not of an absolutely uniform density in all its parts. It is quite sufficient to compress the body, even only with the

and, a little more on one side than the other to make the ware warp.

Even considering these difficulties, the different methods already mentioned (Chapter IV.) can be used for moulding porcelain.

We will just repeat them quickly, only remarking on the special peculiarities for porcelain.

*Throwing* can only consist of the rough form, because the slight plasticity of the body necessitates the walls being of an undesirable thickness. It ought always to be finished off by the body being turned after having been dried a little, or even when quite dry. As the quantity of the body to be taken off is important, during this latter operation there are formed a great many scraps of the body, which are of course put to be used again, and, besides, a rather thick dust, which is inconvenient and hurtful to the health of the workmen. It is necessary to breathe this through ventilators, or at least to give the workmen a mask.

*Expression*, which is made difficult by the small plasticity of the body, is scarcely used, except for taps, or for little special pieces.

*Moulding by hand* in plaster moulds needs very particular care, so as to press the body equally into all parts of the mould and to make the joints. Batts of the body must always be used that have themselves been made with as much care, not lumps but moulded pieces. Besides, these batts ought to be cut out exactly in such a way as to correspond, when put together, with all the changes of the mould. They rest on a cloth or on a damp leather, which is used to lift them up and to put them into the mould. When they have got into a suitable position the cloth is taken away, and the body is pressed lightly by means of a sponge, at the same time the joins that are necessary being made. The body being dry, this moulding is followed by a trimming, in which the ridges are removed, the edges are rounded, etc. This operation also produces rather a large amount of dust, and would need the use of the same methods of prevention as the turning.

*Moulding on the jolley* is the most usual method of working for porcelain, not only because it is the most convenient, but

also because most of the porcelain goods are of a shape that lends itself to it. It is always preceded by throwing the batt for the flat pieces, the cover for the hollows, which are made on the wheel, giving them a very regular form and smoothing the surfaces, as this is an indispensable condition. The batt, or shape, having been applied on or in the mould, it is pressed down by means of a sponge, beginning always at the centre. For narrow vases into which the hand cannot be put, the sponge is fixed on a stick, as we have already said.

The piece having thus taken its definite shape from the side of the mould, it is only in exceptional cases that the other face can be simply moulded by the sponge. Almost always it is necessary to have a second special moulding. In Germany and Austria this is chiefly done with templets, as already described (Arts. 109 and 261). In France turning the stiffened body is preferred, this being done according to the shape of the pieces on vertical or horizontal lathes, the body being still in the mould. For some pieces they can wait until they are sufficiently dry to be able to be put direct on to the wheel. The two methods, by templet or by turning, have their disadvantages and their advantages. In theory the second one makes pieces better as to quality, but it needs very skilful workmen.

For flat pieces the following method of working can also be used, called jiggering, which was invented at Limoges by M. Faure.

The tools used for this purpose allow of moulding on the jigger with templets of all open hollow goods, that is to say, those that lend themselves to outside mouldings: plates, stewed fruit dishes, bowls, etc. They are made in four operations:—

1. Making the batt, by using the method shown in Fig. 97 (page 217).
2. Putting the batt in the centre of the plaster mould.
3. Making the outside shape with a templet.
4. Turning the edges.

As we have already said, the batts are moulded on a skin stretched round a copper ring, which is itself fitted on to the head of the machine. In the centre is placed a lump of clay of a definite size, and the machine is set in motion; the templet

descends automatically, and ascends in the same way. The batt, when finished, is taken up with the skin and the disc, and the whole is placed under the circular plate of the shaping machine. This plate is lowered in such a way as to place the batt on the plaster mould; then it is taken off by putting between it and the leather a wooden knife. The plate is raised, the wheel is started by leaning on the pedal, and the batt is pressed by hand on to the mould with a sponge, passing from the centre to the circumference, to prevent any air remaining between the mould and the batt.

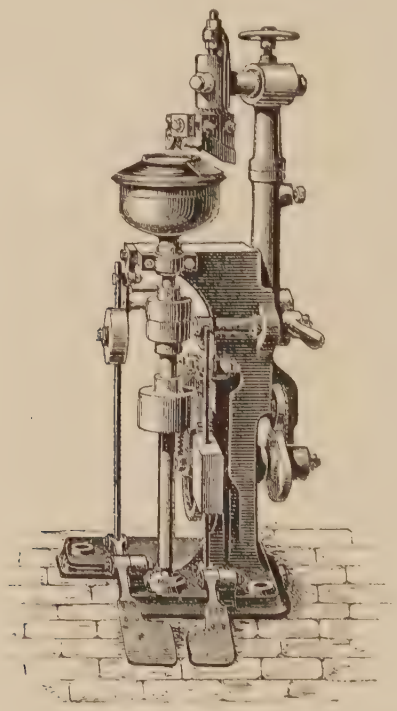


Fig. 318.—Mechanical Making of Plates.

The bending being finished, the mould is taken away and placed on the head of the jigger (Fig. 318). This latter is started by leaning on the pedal at the left. A first tool starts from the centre and going outwards forms the bottom, then it is raised to shape the foot, and descends again along the edge. This kind of forming being finished, a second tool, which is a real templet, is lowered and gives the final shape. The yield of this machine is about sixty plates an hour.

It is arranged in such a manner as to be able to obtain all round forms by regulating, by means of an upper screw, the course of the templet and by using templets with different profiles.

The ware thus cut by the templet is lastly placed on the third wheel, where the edges are rounded off and made thinner.

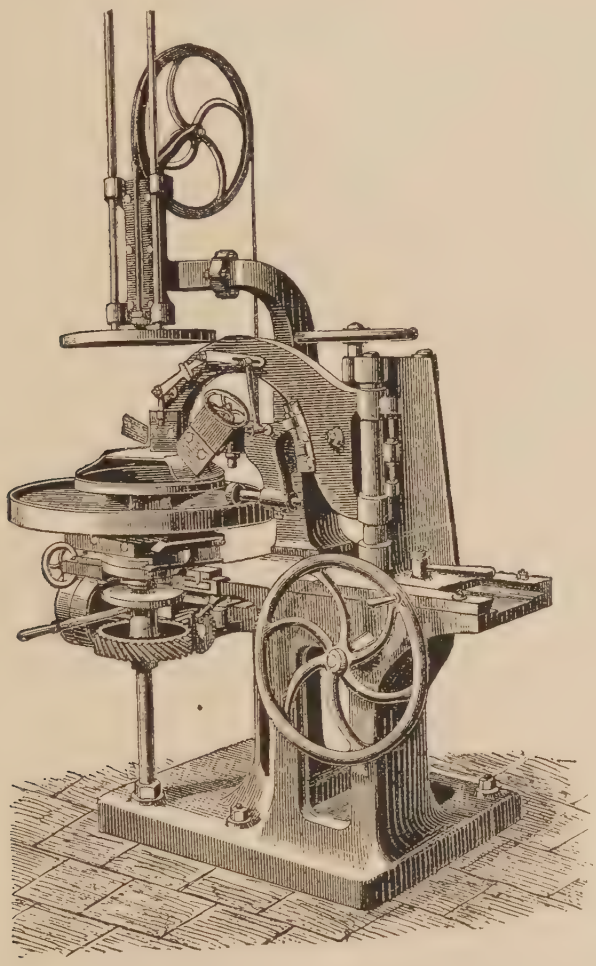


Fig. 319.—Wheel for forming Oval Pieces with a Templet.

M. Faure also constructed a machine, shown in Fig. 319, for making oval dishes. The batt having been made as we have just said, it was shaped by means of a plate balanced and guided by two stems; then, this plate having been raised again, the frame carrying the templets is made to revolve, these are

put in contact with the batt, and the wheel, which is furnished with an arrangement to give it an oval motion, is started. The templets are arranged as in the preceding machine, only with this difference, that the part of the templet that forms the edges is moved with a slightly oscillating motion, which is made necessary by the greater width of the edges on account of the large axis of the dish, as this necessitates the inclination of them being modified. This oscillating motion is transmitted to the templet by a series of levers worked by a roller, under which turns the rim of a large plate placed under the mould. This rim has various heights; it is raised more in the parts which correspond to the long axis, so that it raises progressively the roller, to let it descend again, thus modifying the slope of the templet.

*Moulding in a press* is scarcely ever used except for small objects. In that case it is usually done by first throwing the body and compressing it by hand afterwards between two plaster moulds. The repressing of the stiffened body is employed for some special pieces, of which we shall speak further on.

*Moulding by casting* is very suitable for the very thin body that is used for porcelain, and it is very widely used for the making of a number of objects with thin sides, which it would be very difficult, if not impossible, to obtain by the other processes. This method of fashioning them was described in Art. 112. As the thickness of the body, which is put in in the regular way, is almost uniform, it can be varied by diminishing the absorption of the plaster in certain parts, or else by adding a little body by hand and by the sponge while the piece is still in the mould.

The *finishing* in the manufacture of porcelain is more important than in any other ware. The different operations that it needs have been described in Art. 113; there is no need to repeat them here.

291. **Drying, Warming, and Application of the Glaze.**—The drying of thin and porous pieces, such as the bodies of manufactured porcelain are, does not present any difficulty. It takes place nearly always in the places where they are moulded, which are provided with heating apparatus as well. Yet arti-

ficial drying sheds can be made use of similar to those employed in faience works, especially for drying the moulds.

We said that, in order to facilitate the application of the glaze, the bodies were heated a first time to a temperature of about 800° C., using the waste heat from the kilns employed for burning them. This preliminary heating, which for some pieces is not indispensable, ought not to be considered as a burning, but as a stage of the manufacture. If for this purpose the body has to be heated to a temperature sufficiently high in order to become somewhat resistant, it must, on the other hand, be guarded from too high a temperature, which would have the effect of diminishing its porosity too much, and make it incapable of fixing the glaze. This heating is done in saggers, the saggering, which is very simple, being done in bulk in the inside of the same sagger.

The ware which has been heated is afterwards carefully dusted, then covered with glaze. This latter is in the form of a liquid paste, of a consistency which can be varied according to the thickness of the layer which is desirable. The thickest goods, naturally, ought to have a stronger layer than the thin ones. It is nearly always applied by immersion; it is only for very fragile pieces that it is done by spraying or by powdering. The layer of glaze dries rather rapidly in contact with the porous body, and at the end of a short time the burning can be proceeded with.

**292. Burning.**—Round kilns with ascending flames, heated by wood, were for a long time exclusively used for burning porcelain. Then the wood was replaced by coal, and descending flames substituted for ascending ones. Fig. 162 (page 360) shows the arrangements generally used at the present time. The dimensions of these kilns vary very much, but in order to obtain a suitable distribution of the heat it is wise not to have the interior diameter more than 16 to 19½ feet. The height of the burning space is a little less than the diameter. As to the dome, it may be a little smaller than the burning space, because the saggering of the wares that are not covered with glaze takes less room. The number of fireplaces varies from three to eight.

The slow firing is relatively short and easily managed on

account of the very slight amount of damp that the goods contain. The same applies to the commencement of the hard firing, up to about 1,200° C. From that time the atmosphere of the kilns ought to become reducing in order to avoid the yellow colour due to the peroxide of iron that all bodies contain, and which should be replaced by the slightly bluish colour of the protoxide. This reducing working would not be difficult to get if there were no risk of running into another fault. In fact, the action of the hydrocarbides is to be feared, as these, by penetrating by diffusing through the walls of the saggers, as we saw in Art. 177, may, by decomposing, leave a deposit of carbon on the ware. When the vitrification takes place this carbon would be incorporated in the mass, and would give it a red colour. We say, then, that the porcelain is smoked. When, in the course of the burning, it is noticed that the atmosphere of the kiln is very clouded by the presence of these hydrocarbides, which have a tendency to accumulate under the dome at the place where the circulation of the gases is least active, then the reducing working must be stopped for some time, and the fireplaces must have an oxidising working, thus trying to burn up the deposited carbon. The firemen, in their expressive language, call this modifying of the working by the name of washing the kiln.

We can understand that it is not easy to find the true medium between an oxidising atmosphere or a neutral one and an atmosphere that is too reducing, especially where the fireplaces are difficult to regulate, such as are still frequently employed. It is also very necessary that the atmosphere of the kilns should be as uniform as possible, that there should not be parts where it is extra-reducing. This condition can only be obtained by a rational arrangement of the fireplaces. It is equally indispensable that all the burning space should be under pressure to prevent the air getting in through the walls and cracks. For that purpose the openings for letting off the gases are made of rather narrow section, and the channels for the smoke are allowed to be made wider.

The dimensions of the hearths depend on the volume of the burning space, and especially on the fuel; it is therefore absolutely impossible to give precise directions in relation to them,

because we can give examples of kilns that are working suitably in which the dimensions of the grating vary from one size to the double of it. As a general rule the hearths used in France are too small, or else purer fuel should be used. The length of the burning varies from eighteen to thirty-six or even forty hours. Naturally, it is to one's interest to hasten it as much as possible, at the same time not passing certain limits necessitated by the resistance of fireproof materials to a rapid increase in the temperature.

The first part of the cooling should be in a reducing atmosphere, until the glaze is solidified. After that the atmosphere may be neutral, then below 800° C. it may be oxidising without any bad effects.

The thermic balance-sheet in this class of kiln may, in a very general and approximate way, be set down as follows:—

| | | | |
|---|---|---|---|
| Heat produced by combustion | 100 | Heat theoretically useful | 10 |
| | | Heat used in the globe | 6 |
| | | Heat lost in charging | 38 |
| | | Heat lost by the heating of the walls | 12 |
| | | Heat lost by radiation | 10 |
| | | Heat lost through the chimney | 20 |
| | | Heat lost by the reducing working | 1 |
| | | Heat lost by incomplete combustion | 3 |
| | 100 | | 100 |

Fig. 163 (page 362) represents a kiln of the same kind, but in which the "globe" is below the burning space, and this necessitates there being an independent chimney. In theory this type of kiln seems preferable to the preceding one.

At the Berlin manufactory a kiln with continuous firing has been used for a long time, which is constructed on the system which is represented in Fig. 306 (page 678). As the general working of the continuous kilns is always decidedly oxidising, in this kiln they have not been able to get the reducing atmosphere which is necessary for burning porcelain, except by various expedients, the principal one consisting of cooling rather rapidly the compartment of which the burning has just been finished, so as to solidify the glaze and thus protect the body against the oxidising action of the air. The results attained by this kiln were not satisfactory enough from

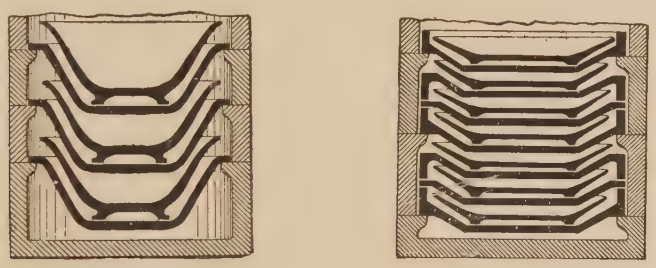
an economical point of view to induce the German porcelain makers to imitate this example.

We do not think that, in the present state of the porcelain industry and of the knowledge of industrial physics, burning with a continuous firing can be used with any great advantage. We would repeat on this subject the argument that we used as to burning faience (Art. 263), but with this aggravating circumstance, that the economy would reach scarcely 10 or 15 per cent., and would be compensated by the annoyances of a much longer burning and important modifications in existing factories. Rather would we copy the Chinese and use some kinds of semi-continuous kilns. Yet we believe that progress may be made, but more by better construction of the present kilns, and by using gas heating when fuel can be procured cheaply, that is suitable for burning in gas generators and which cannot be used in furnaces with hearths.

**293. Saggering.**—The great trouble of burning porcelain, looked at from all points, is saggering. Nearly all pieces have to be supported separately, therefore it is necessary to use not only saggers, as in faience, but also to place supports in them, which naturally increases the dead weight as compared to the useful weight. Besides, the high temperature at which they are burnt necessitates the using of saggers and supports made of fireproof materials of superfine quality; the wear of them is also very considerable. If we notice that the dead weight is usually four times the weight of the pottery, and that the supports must be set in so that the ware will not get out of place, we shall understand the important part that saggers play in the manufacture of porcelain.

The piles of saggers are arranged in the kilns in the same way as when burning faience, but the saggering is entirely different. In theory, each sagger is composed of an outer part, which is usually circular, and of a support suspended inside, so that there is only one piece in a sagger. Fig. 320 shows an arrangement of this kind. For very flat objects, such as plates, we can manage to put three pieces in a sagger, by using the arrangement shown in Fig. 321. In these two examples, the wares rest on their feet, the lower surface of which that is in

contact remaining unglazed without any disadvantage. Besides, they can be prevented from sticking by powdering the bottom of the sagger with a little quartzeous sand or by smearing the part in contact with a little fireclay. In some special cases it is better to put the objects on their upper edges, but these edges, being necessarily left without glaze, should afterwards be gilded. Some larger pieces, or those whose foot is too small, ought to be supported to prevent them getting out of shape or sinking down. The parts in contact with the supports must remain unglazed, and are decorated later. In some cases the ware is obliged to be held up from the inside by means of pieces or supports of unburnt body. These pieces can naturally only be used once. Lastly, for goods of large dimensions, it is necessary to construct in the kiln real muffles, which are usually placed on the top of several piles of saggers.



Figs. 320 and 321.—Méthods of Saggering.

Such is a very brief summary of the principles of saggering porcelain. The application of them needs a great deal of practice, much care, and the knowledge of a number of little special expedients.

Burnt ware that has the foot slightly out of shape can be touched up on horizontal mills of cast iron, that are turned very quickly, and are covered with sand and water, similar to those used for polishing stove tiles. Polishers are also used for taking off the little grains of sand or the pieces of the saggers which very often fall on to the ware while it is being burnt and become incorporated in the glaze. These polishers, which are like those used in glass making, are of hard stoneware, or of a mass, composed of porcelain body with the addition of some quartz, which has been heated through.

294. **Decoration.**—The decoration of hard porcelain presents some peculiar difficulties. We have seen that, as regards the *decorative moulding*, the slight plasticity of the body makes it very difficult to manufacture a number of objects, the execution of which, on the contrary, would be relatively easy in faience or stoneware. Doubtless the Chinese found out some expedients in moulding, but the body they use is more plastic than ours, and the hand labour is not so dear.

Decorating with colour presents difficulties of another kind. On account of the high temperature at burning takes place, there is only a small number of colouring materials which can be employed for hard firing.

The *colouring of the body* can be obtained by some of the following colours :—

*Blues.*—Oxide of cobalt, the shade being modified by a mixture of oxide of chrome or oxide of uranium. It is necessary to frit the oxide of cobalt with zinc first, before mixing it with the body.

*Grey.*—Oxide of iridium and platinum. The shade can be made prettier by a mixture with oxide of cobalt.

*Yellow.*—Oxide of uranium.

*Browns.*—Mixtures in various proportions of chromate of iron and oxide of manganese.

*Rose.*—Mixture of alumina anhydride and chromate of potash, first heated in the hard firing with an oxidising atmosphere, and afterwards added to the body.

The introduction of these colouring materials into the body naturally has the effect of making their fusibility vary, and it is necessary to modify the composition of them by the addition either of kaolin or else feldspar.

The *under glaze colour* is very little used on account of the difficulty of putting it on the biscuit, and in consequence of the small number of colours that can be employed. Only one, oxide of cobalt, has sometimes been made use of. Yet the oxides of uranium, chrome, iridium, and a mixture of chromate of iron and oxide of manganese, etc., might also be used. These oxides are generally mixed with some of the body, heated in the hard fire, and then put on to the biscuit. It is then necessary to fix the

colour by warming the body through before the glaze is applied. Generally, the colours thus obtained are a little dull, on account of the opaline transparency of the glaze.

It has been tried to put the colour on the unburnt glaze, but it is difficult to apply it, and this process is scarcely ever employed.

*Over glaze colouring* can be obtained in *hard firing* by putting the colour on the vitrified glaze and heating it a second time in saggers, with an ordinary burning. The colours used thus have a flux added to them, which is the ordinary glaze, more or less modified by the addition of some alkaline-earthy bases.

M. Peyrusson has specially studied this kind of decoration, and has arrived at making a sufficiently extensive pallet.

Theoretically, in order to prevent the action that the flux may exercise on the colour, it is necessary first to give the composition of light red to the latter, that is to say, to combine a protoxide with a sesquioxide. The colour, when thus composed, may be represented by the formula

$$RO, R^2O^3,$$

in which RO represents a colouring protoxide or an alkaline earthy base, and $R^2O^3$ some alumina or a colouring sesquioxide. Among the combinations of this kind that are the most used we may mention :—

| | |
|---|---|
| Aluminate of cobalt . . . . | $CoO, Al^2O^3$ |
| Aluminate of zinc and cobalt . . | $\left\{\begin{matrix} ZnO \\ CoO \end{matrix}\right\} Al^2O^3$ |
| Aluminate of chrome . . . | $CrO, Al^2O^3$ |
| Chromate of cobalt . . . . | $CoO, Cr^2O^3$ |
| Chromate of iron . . . . | $FeO, Cr^2O^3$, etc. |

These compounds, having been heated in the hard fire, are ground and a flux is added to them.

On the other hand, other very stable oxides, such as those of titanium, uranium, platinum, iridium, can be used direct.

The colours thus obtained are black, blue of different shades, emerald green, yellow, various browns, rose, brick red. This method of decoration in the hard firing, without having the brilliancy of the transparent enamels of faience, is yet of a much richer and more brilliant colouring than that which can possibly be got with muffle firing.

*Over glaze colouring with muffle firing* is, however, much more used. It is based on the employment of the vitrifiable colours of which we spoke in Art. 193, the burning being done in a muffle at the test for gold.

These vitrifiable colours are most often manufactured in special works, and can easily be procured in commerce. Yet some factories prepare them themselves, at least in part. The colouring oxides are, as we said, mixed with fluxes; the following is the composition of the principal ones, with the names given to them in the vitrifiable colour trade :—

*Rocaille Flux.*

| | |
|---|---|
| Oxide of lead | 75 |
| Silica | 25 |

(Used for blues and the reds from iron.)

*Flux for Greys.*

| | |
|---|---|
| Oxide of lead | 66 |
| Silica | 22 |
| Melted borax | 11 |

or

| | |
|---|---|
| Oxide of lead | 60 |
| Silica | 15 |
| Melted borax | 25 |

(Used for greys, yellows and light browns.)

*Flux for Carmine.*

| | |
|---|---|
| Oxide of lead | 11 |
| Silica | 33 |
| Melted borax | 55 |

(Used for carmine and light purple.)

*Flux for Purple.*

| | |
|---|---|
| Oxide of lead | 37·5 |
| Silica | 12·5 |
| Melted borax | 50·0 |

(Used for purple and the violets made from gold.)

*Flux for Violet.*

| | |
|---|---|
| Oxide of lead | 67·5 |
| Silica | 5·0 |
| Melted borax | 27·5 |

(Used for violet.)

*Flux for Green.*

| | |
|---|---|
| Oxide of lead | 73 |
| Silica | 18 |
| Melted borax | 9 |

or

| | |
|---|---|
| Oxide of lead | 70 |
| Silica | 10 |
| Melted borax | 20 |

(Used for the chrome greens, blue greens and yellow greens.)

*Flux for Turquoise.*

| | |
|---|---|
| Oxide of lead | 35 |
| Melted borax | 65 |

(Used for turquoise blue, sea green.)

At the low temperature of the muffle firing all the colouring oxides can be employed; there is therefore no need to repeat this subject. The colour is applied either with a brush, or else by chromolithography (Art. 193).

All the other processes for decoration already described, gilding, silvering, putting on platinum, lustres, etc., can naturally also be employed.

In Fig. 178 (page 376) was represented the type of muffle

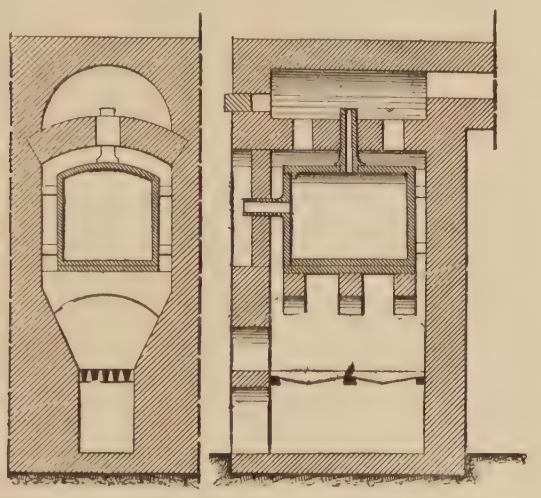


Fig. 322.—Muffle Kiln.

kiln in general use. For large quantities a series of muffles side by side are sometimes used, so as to obtain a heating with continuous or semi-continuous firing. For small quantities, or for heating pieces that need special care, little muffles are used, such as those shown in Fig. 322.

In any case they are charged in slips, and, except in some special cases, as, for example, for metallic lustres, the working of the fire is always decidedly oxidising.

**295. General Arrangements of Porcelain Works.**—The manufacture of hard porcelain is concentrated in France, except in some rare instances, in the departments of Haute-Vienne and

Cher. In Germany it is more scattered, but the principal centres of production are to be found in Saxony, Bavaria, Thuringia and Silesia. In Austria, on the contrary, it is concentrated in Bohemia. There are also some factories in Belgium, Denmark, Russia (Finland and Poland), Italy (Tuscany), the United States (New Jersey and Ohio), China (Kiang-Si), and in Japan. We know that hard porcelain is not made in England.

The porcelain works have generally been placed in the neighbourhood of the beds of kaolin and fireclay. In some cases, on the contrary, it is the neighbourhood of coal mines or forests that has been taken into consideration.

In a general way it is agreed that, for manufacturing 1 cwt. of porcelain, 8 cwt. of various raw materials must be used: fuel, fireclay, kaolin, feldspar or pegmatite, quartz, plaster (for the moulds), etc. As all these products cannot be found in one single locality, it is necessary, in choosing the site for a new factory, to take into account the different expenses of transport, and especially that of the fuel. It is equally necessary to think about hand labour, because professional skill plays a large part in moulding, saggering and decoration.

As in faience factories, the manufacture is done in buildings with several storeys, the preparation of the body and the making of the saggers being on the ground-floor, the moulding and decoration in the upper storeys. The kilns are generally placed outside, but near the buildings.

### (*b*) *Porcelain for the Fire.*

**296.** By this name are called porcelain objects intended for heating liquids. They are used in chemical industries, in laboratories, and for domestic purposes. They are capsules, retorts, crucibles, tubes, saucepans, dishes, coffee pots, etc.

The composition of the body scarcely differs from that of the other hard porcelains, yet, in a general way, it is less silicious and more aluminous. For example, the following is the composition of the fire porcelain from Bayeux, which is thought a great deal of in France:—

| | |
|---|---|
| Silica | 61·61 |
| Alumina | 30·01 |
| Oxide of iron | 1·56 |
| Lime | 3·56 |
| Potash | 3·26 |

The body when burnt is less translucid than that of the porcelain for table ware, but it resists better the sudden changes of temperature. It ought to be manufactured with an argillaceous kaolin, or, if that cannot be got, by an addition of a certain proportion of plastic clay. There is no difference in the manufacture of it and of what has just been described, the more plastic body lending itself better to moulding. As the objects ought to be thin, so as to be better able to resist the inequalities in expansion, they are frequently moulded by casting.

Porcelain for the fire is manufactured by some porcelain factories, which make a speciality of it.

### (c) *Porcelain for Electrical Conduits.*

**297.** The non-conductibility of porcelain causes it to be employed in the making of insulators for electrical conduits. For a long time that use was limited to the making of insulators for the telegraph, it has now extended to a rather large number of objects in current use in the distribution of the electric light. Fig. 323 represents some of these uses.[1] The bodies employed ought to be rather plastic, so as to lend themselves to a moulding which is often complicated, the transpareney being evidently quite a secondary matter. In theory, they are fashioned by casting them in a mould, this being followed by the body, when stiffened, being repressed, with strike presses, the whole being sometimes completed by finishing on the lathe, which is specially intended to perfect the filleted parts. We thus produce objects which, as the latter engravings in Fig. 323 show, are so exact, that they seemed, even a few years ago, to have been made by machine.

The manufacture has become the speciality of some porcelain factories in Germany, France and England.

[1] These engravings are from the catalogue of MM. Parvillée Frères et Cie.

### (*d*) *Porcelain for Mechanical Purposes.*

298. The hardness of porcelain, and its resistance to cracking, allow it, in some cases, to be employed for mechanical purposes. The principal object, then, is to prevent contact between the metal and the materials to be ground or powdered. Every one knows the porcelain mortars that were used in laboratories for a long time. On the other hand, we have already spoken

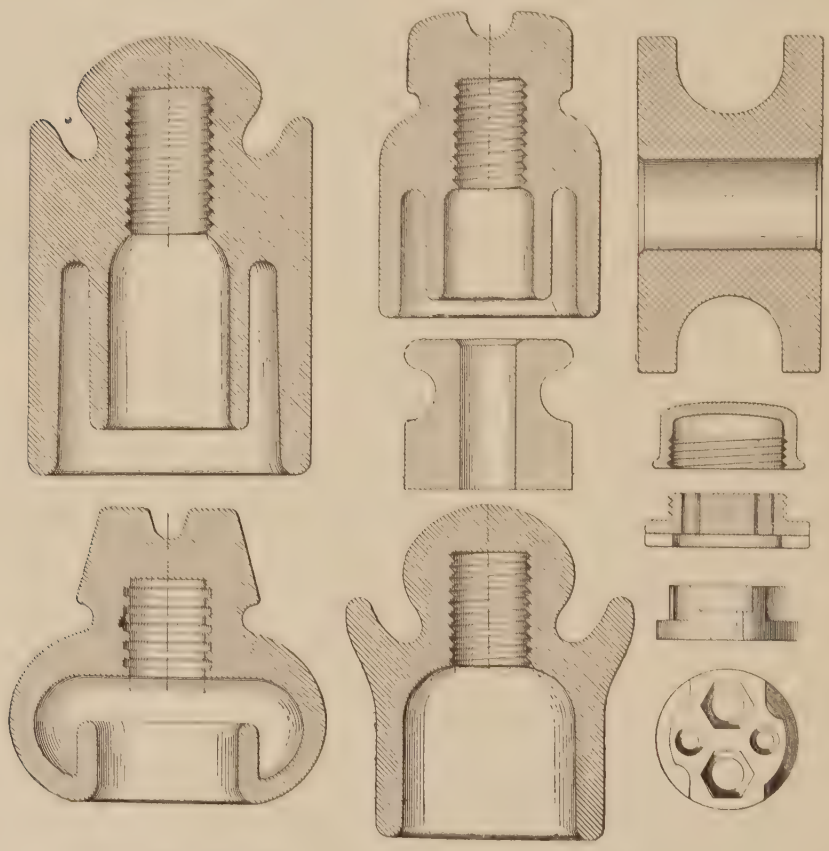


Fig. 323.—Porcelain Objects for Electrical Channels.

of the coverings of stoneware, or, better still, of porcelain, that are used in Asling cylinders. Lastly, M. Wegmann has, more recently, used porcelain for making the outer covering of the mills for grinding corn. In the last case, the ware is unpolished. As it is especially necessary to have a very hard article, and one of very exact shape, it is made as we have just said in speaking of the porcelains used for electricity. After being

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thrown in the mould, the stiffened body is repressed with hydraulic presses. There is nothing particular as to the burning in the hard firing, but it is afterwards necessary to turn the shape very exactly. This is done by means of a tool in black diamond, the only material that can be used in the trade whose hardness is greater than that of the porcelain.

We are certain that there are still a large number of cases in which, in machinery, the remarkable qualities of hard porcelain could be used with advantage.

### (*e*) *Architectural Porcelain.*

**299.** The Chinese have for a long time used porcelain in architectural decoration, and even in the construction of the walls. The famous porcelain tower of Nanking dates from the dynasty of the Thai-Yong-Youen (954 to 1368). Yet porcelain is not suitable for making thick materials, not only on account of its high price, but especially in consequence of its great shrinkage, which makes it, so to speak, impossible. We can, it is true, get over this difficulty by making the materials hollow, with relatively thin sides, but as the object is evidently only to make the outside that is seen of porcelain, we fall back on wall tiles as the best.

For architectural decoration evidently porcelain can be used, but in that case we do not see what advantage there is over stoneware, while its high price, and especially the difficulty of making it, are serious drawbacks. Extreme hardness and transparency, these two qualities, which make hard porcelain the most perfect material for table ware, lose their importance when monumental pottery is wanted. So as not to be too dogmatic, we may admit of the use of architectural porcelain for some fine, thin decoration with sharp edges, but we do not think that this use will ever be greatly extended.

### (*f*) *Dull Porcelain, called Biscuit Porcelain.*

**300.** The body for hard porcelain can naturally be burnt directly in the hard fire without being covered with a glaze. The goods thus obtained are very improperly called by the name

of biscuit porcelain[1]; they consist principally of statuettes or other decorative objects.

The most plastic porcelain body is almost always used, called body for sculpture, which is also used in the making of other decorative porcelain. When a special body is prepared it is given a composition akin to that used at Sèvres. Seger indicated the following composition as giving very beautiful productions :—

| | |
|---|---|
| Silica | 58·3 |
| Alumina | 33·2 |
| Oxide of iron | 0·5 |
| Lime | 0·8 |
| Alkalies, chiefly potash | 7·2 |

It is formed of fifty-four parts of Zettlitz kaolin, forty-five parts of Norwegian feldspar, and one of marble, mixing 30 per cent. of cement of the burnt mass to 70 per cent. of the raw body. The burning takes place at No. 9 of Seger's tests.

The moulding, saggering and burning of these dull porcelains are done in the same manner as for glazed porcelain.

The only thing to be noticed is that the body must remain dull and not commence to vitrify, which would give it a greasy, shiny look which is not agreeable.

### 2. *Soft Phosphated Porcelain, called English Porcelain.*

**301.** Among the different sorts of tender porcelain, the only one that has any industrial importance is the phosphated porcelain, almost exclusively manufactured in England. This porcelain has the great advantage over hard porcelain that it requires a much lower temperature for burning it, and consequently of being less costly and easier to decorate. Although moderately translucid, the body is milky white, resembling alabaster. On the contrary, the great disadvantage of it is the one which prevents its being taken up outside England, namely, its lack of hardness and its quickly wearing away when used for table. It is very curious that the English continue to prefer this porcelain, one of the first kinds discovered, when they could so

[1] It is probable that porcelain heating has been called by the name of biscuit from the similarity of look between it and some food stuffs, but it is entirely wrong to give the same name to unglazed porcelain burnt in hard firing, which has not at all the same appearance. In any case, this title does not indicate a double burning.

easily manufacture hard porcelain, which is preferred in all other countries.

The body varies somewhat in composition. The following, according to Prössel, are some examples of the mixtures, but simply by way of suggestion:—

| | | | | | | |
|---|---|---|---|---|---|---|
| Kaolin | 30 | 28 | 23 | — | 23 | 30 |
| Pegmatite | 18 | 30 | 31 | 23 | 27 | 7 |
| Plastic clay | — | — | — | 23 | — | 4 |
| Quartz | — | — | — | 14 | — | 3 |
| Biscuit cement | 5 | — | — | — | — | — |
| Calcined bones | 47 | 41 | 46 | 46 | 46 | 50 |
| Alkaline frit | — | — | — | — | 3 | 6 |

This frit is composed of

| | |
|---|---|
| Pegmatite | 56 or 60 |
| Quartz | 20 ,, 30 |
| Soda | 8 ,, — |
| Borax | 8 ,, 10 |
| Oxide of zinc | 8 ,, — |

Plastic clay is only added to the bodies in order to increase their slight plasticity. It thus makes them more easy to mould, but at the expense of their translucidity and whiteness; also, the bodies which contain any are only used for making porcelain of inferior quality. The special characteristic of this porcelain is the use, in the composition of the body for it, of a very large proportion of calcined bones (see page 82), which are composed chiefly of phosphate of lime, a little carbonate of lime and some traces of carbonate of magnesia.

This composition of the glaze is very nearly that for feldspathic faience, that is to say, that it is alkaline-boracic plumbiferous.

These are three examples of the composition:—

*Frit.*

| | | | |
|---|---|---|---|
| Kaolin | 34 | — | 12 |
| Pegmatite | — | 38 | 20 |
| Quartz | 14 | 24 | 15 |
| Carbonate of lime | 18 | 11 | 18 |
| Borax | 34 | 27 | 35 |

*Glaze.*

| | | | |
|---|---|---|---|
| Frit | 70 | 60 | 65 |
| Pegmatite | 9 | 20 | 11 |
| Quartz | — | — | 11 |
| White lead | 21 | 20 | 13 |

The body is naturally prepared by the moist method; yet

in most factories the measuring is done at the present time with the raw materials in a powder and not in slip. The body, which is only slightly plastic, presents the same difficulties in moulding as that for hard porcelain. The most usual method is moulding on the wheel, or, much more rarely, by hand in plaster moulds. The warming through is also done in the "domes," the pieces being charged in bulk in saggers. However, for the best qualities of body, that is to say, those richest in phosphate and alkalies, it is necessary to dust over the surfaces that come in contact with some quartz, so as to prevent them sticking. The temperature at which the biscuit is burnt is nearly the same (although perhaps a little higher) as that for burning feldspathic faience, consequently the two wares are sometimes burnt simultaneously.

As the biscuit is scarcely porous, the glaze ought to be rather thick, it being applied by immersion.

The thickness of the layer of glaze is less than for hard porcelain.

The hard firing is done in the same way as for hard porcelain. Yet the saggering is relatively easier. It is mostly done by using the method shown in Fig. 293 (page 653).

The colouring may be under glaze, by the processes employed for feldspathic faience, or over glaze, as has just been described for hard porcelain. Lithographic printing over glaze is also frequently employed, the decoration being touched up with vitrifiable colours put on with a brush. The backgrounds can be made by covering the glaze with a lithographic varnish and dusting on some vitrifiable colour. The methods of decoration are, as we have seen, more numerous than for hard porcelain and the muffle colours are more brilliant, because the glaze, which is more fusible, agrees better with the vitrifiable colours. Yet all these advantages are acquired at the expense of solidity; besides, the decorated English porcelains are rather objects of luxury than objects for everyday use.

The manufacture of phosphated porcelain, as well as that of faience and fine stoneware, is done in England in Staffordshire, where a great many factories produce all three kinds of ware at the same time.

### 3. *Soft Vitreous Porcelain, called French Porcelain.*

**302.** This porcelain, which is also sometimes called by the names of fritted porcelain or Réaumur porcelain, was, as we have seen in the history of pottery, the first that was made in France. The discovery of hard porcelain caused it to be abandoned. Yet, from time to time, new trials of making it are taken up, but generally they are of short duration. As already remarked, this material is not a ceramic production, so to speak, but a glass. Its use, its appearance, and the processes of its manufacture, however, cause it to be classed among pottery. The body was composed in the following manner.—

*Frit.*

| | |
|---|---|
| Fontainebleau sand | 60·0 |
| Saltpetre (mineral crystal) | 22·0 |
| Grey sea salt | 7·2 |
| Rock alum | 3·6 |
| Alicante soda | 3·6 |
| Montmartre gypsum | 3·6 |

*Body.*

| | |
|---|---|
| Frit | 75 |
| White chalk | 17 |
| Calcareous marl from Argenteuil, washed | 8 |

Only the parts of the frit that were quite vitrified were used; these were ground and added to the chalk and marl, then ground again in water, in such a way as to obtain an absolutely impalpable paste. This was dried, then turned again into a paste by the addition of some water, green soft soap, and parchment size.

The fashioning, which was very difficult on account of the almost entire absence of plasticity, could only be done by moulding, putting a thick layer of body into a plaster mould that had the outside form of the object, and compressing it with a chuck, also of plaster, which roughly represented the form of the inside space, only smaller. When dried, the making was finished by turning.

The burning was entirely different from that of hard porcelain, in fact, it consisted, as in the case of faience, of a first heating, which vitrified the body; a second burning, intended to fix the glaze, being at a lower temperature. For the first burning the saggering was very difficult on account of the softening and

great shrinkage of the body. The objects were obliged to be held up with supports of a suitable shape, made of raw body, that would shrink the same as the ware.

The glaze was composed of

| | |
|---|---|
| Litharge . . . . . | 38 |
| Fontainebleau sand . . . . . | 27 |
| Calcined flint . . . . . | 11 |
| Carbonate of potash . . . . . | 15 |
| Carbonate of soda . . . . . | 9 |

It was melted, then ground two or three times, powdered and put on by pouring. The second burning was easier, the pieces being simply stood on their bases, either in glazed saggers or in muffles.

The colouring was naturally over glaze only, the colours having the addition of a rather small proportion of alkaline fluxes. They are rather brilliant, and harmonise remarkably well with the glaze.

We may remark that the body is a silicate of lime and alkalies, containing very little alumina, and it may be approximately represented by the formula :—

$$\left.\begin{array}{l} 0{\cdot}70CaO \\ 0{\cdot}15K^2O \\ 0{\cdot}15Na^2O \end{array}\right\} 0{\cdot}07Al^2O^3,\ 3{\cdot}5SiO^2.$$

If we compare it to that of plate glass,

$$\left.\begin{array}{l} 0{\cdot}20CaO \\ 0{\cdot}80Na^2O \end{array}\right\} 0{\cdot}08Al^2O^3,\ 3{\cdot}8SiO^2,$$

we see that, except for the division of the fluxes, there is a complete analogy between them.

As to the glaze, that corresponds nearly to the formula

$$\left.\begin{array}{l} 0{\cdot}46PbO \\ 0{\cdot}31K^2O \\ 0{\cdot}23Na^2O \end{array}\right\} 1{\cdot}72SiO^2,$$

that is a glass analogous to strass.

Vitreous porcelain is then a hard glass, heated to a temperature that is not sufficient to melt it, but enough to give it a milky transparency, which is covered over with another soft glass.

This porcelain was manufactured at Sèvres, Saint-Amand, Saint-Cloud, Sceaux, Mennecy, Tournay, and Arras.

4. *Soft Vitreous Porcelain, called New Sèvres Porcelain.*

**303.** In 1884 the manufacture of Sèvres, after long experiments for the purpose of finding a porcelain which would lend itself better to decoration than hard porcelain does, and especially that would take the turquoise blue from copper, brought out a new kind of ware, to which the name of New Sèvres porcelain was given.

The following are some particulars about this ware, which are based chiefly on the work by MM. Lauth and Dutailly, entitled *Experiments on Porcelain.*

The body is composed in the following manner:—

*Frit.*

| | |
|---|---|
| Sand | 77 |
| Carbonate of soda | 8·5 |
| Saltpetre | 16·5 |
| Chalk | 18·4 |

It is a true glass, which is melted, then powdered in water. Then its composition is:—

| | |
|---|---|
| Silica | 77·0 |
| Lime | 10·3 |
| Potash | 5·0 |
| Soda | 7·7 |

It enters into the composition of the following body:—

*Body.*

| | |
|---|---|
| Fontainebleau sand | 49·02 |
| Frit | 27·45 |
| Chalk | 16·66 |
| Plastic clay from Dreux | 6·86 |

Consequently, when burned, the composition becomes:—

| | |
|---|---|
| Silica | 80·31 |
| Alumina | 2·62 |
| Potash | 13·27 |
| Lime | 1·50 |
| Soda | 2·30 |

which may be represented by the formula

$$\left.\begin{array}{l} 0{\cdot}81CaO \\ 0{\cdot}06K^2O \\ 0{\cdot}13NaO^2 \end{array}\right\} 0{\cdot}09Al^2O^3,\ 4{\cdot}6SiO^2.$$

We see that this composition is somewhat similar to that of the preceding porcelain, from which it differs only in a larger proportion of lime in relation to the alkalies, and a slightly

greater amount of alumina and silica as compared with the fluxes.

The body, although slightly more plastic than that of French porcelain, is, however, still very weak, and the moulding must certainly present some difficulties that are more easily overcome when objects of luxury are manufactured than when a trade is attempted to be made.

The first burning, which is at a temperature corresponding to Seger's test No. 9, is for the purpose of vitrifying the body; this then is not, as in hard porcelain, a burning into biscuit or a warming through. The saggering is the same as for burning hard porcelain with hard firing.

The glaze is composed of

| | |
|---|---|
| Sand | 25·52 or 35·15 |
| Chalk | 8·60 ,, 7·43 |
| Pegmatite | 65·98 ,, 7·43 |
| Feldspar | — ,, 57·42 |

corresponding to

| | |
|---|---|
| Silica | 75·20 or 75·09 |
| Alumina | 12·26 ,, 12·24 |
| Lime | 5·05 ,, 4·32 |
| Alkalies | 7·49 ,, 8·36 |

The medium composition can be represented by the formula

$$\left.\begin{array}{l}0{\cdot}45CaO\\0{\cdot}55K^2O \text{ and } Na^2O\end{array}\right\} 0{\cdot}64Al^2O^3,\ 6{\cdot}77SiO^2,$$

which, by employing the same notation as for the glazes for hard porcelain (page 707) becomes

$$1{\cdot}0RO,\ 0{\cdot}64R^2O^3,\ 6{\cdot}77SiO^2.$$

This glaze distinctly distinguishes the new porcelain from the French soft porcelain, the glaze of which, an alkaline plumbiferous one, is a "varnish" (*vernis*).

It is applied either by dusting or by immersion, the glaze being vitrified at a lower temperature, and the pieces being charged in saggers without any difficulty.

The decoration, which is the essential purpose of this class of ware, may be either under glaze or with coloured glazes, and naturally over glaze also. The temperature of the hard firing is sufficiently low to allow of the use of the blue from copper and of the reds from iron.

5. *Argillaceous Soft Porcelain, called Seger's Porcelain.*

**304.** This porcelain has been manufactured since 1886 at the factory in Berlin. The following is an extract from the work published at Seger's death by the title of *Seger's Gesammelte Schriften.* Seger's object in seeking a soft porcelain was the same that was followed at the Sèvres pottery when the new porcelain was invented. But the different starting-points led to very different results as well. While at Sèvres they started from French soft porcelain, Seger took as his pattern the Japanese porcelain. The following are the different compositions of the body at which he stopped :—

| | | | |
|---|---|---|---|
| Plastic clay (Löthainer Thon) . . | 31·0 | 15·5 | 15·5 |
| Zettlitz kaolin . . . . . | — | — | 13·0 |
| Sennewitz kaolin . . . . . | — | 19·0 | — |
| Feldspar . . . . . | 30·0 | 30·0 | 30·0 |
| Powdered Hohenbocka sand . . | 39·0 | 35·5 | 41·5 |

| | Pure Clay. | Sand. |
|---|---|---|
| The plastic clay contains . . . . | 81 | 19 |
| Zettlitz kaolin ,, . . . . . | 97 | 3 |
| Sennewitz kaolin ,, . . . . . | 65 | 35 |

On the other hand, the chemical composition is approximately the following:—

| | |
|---|---|
| Silica . . . . . | 77·0 to 77·5 |
| Alumina . . . . . | 17·0 ,, 17·5 |
| Lime . . . . . | 0·30 |
| Magnesia . . . . . | 0·20 |
| Potash . . . . . | 3·75 to 3·80 |
| Soda . . . . . | 0·65 ,, 0·70 |

which can be represented by the formula

$$0{\cdot}38RO,\ R^2O^3,\ 7{\cdot}7SiO^2.$$

If we turn back to the composition of Japanese porcelain (Art. 287) we see that it is almost identical as to rational analysis.

The glaze is composed of

| | |
|---|---|
| Pulverised sand . . . . . | 27·3 or 21·0 |
| Zettlitz kaolin . . . . . | 13·0 ,, — |
| Sennewitz kaolin . . . . . | — ,, 19·2 |
| Feldspar . . . . . | 42·1 ,, 42·1 |
| Marble . . . . . | 17·7 ,, 17·7 |

it corresponds to the formula

$$\left.\begin{matrix}0{\cdot}7CaO\\0{\cdot}3K^2O\end{matrix}\right\}0{\cdot}5Al^2O^3,\ 4SiO^2,$$

which is that for Japanese glazes.

The foregoing tables show that Seger arrived at imitating, entirely from a chemical point of view, the Japanese porcelains, but the same does not apply as far as the physical properties are concerned. Seger's porcelain is less translucent, less hard, rather fragile, of a tint that is almost always slightly yellowish. The body should be plastic enough to lend itself easily to moulding; like hard porcelain, it was warmed through, then burnt in hard firing at a temperature that fused Seger's test No. 9. It is this comparatively low temperature for burning it, the same as for the New Sèvres porcelain, which, as well as its slight hardness, has caused us to put this ware among the soft porcelains.

It naturally is suitable for the same class of decoration as Oriental porcelains, and can only be reckoned, even in the opinion of its inventor, as a pottery for objects of luxury.

### 6. *Dull Soft Porcelain, called Parian Porcelain.*

**305.** The different kinds of soft porcelain of which we have just been speaking can naturally, like the hard porcelains, be burnt in the hard firing without any glaze. Yet up to the present time only the French porcelain has been used for this purpose, and this gives dull ware of a very beautiful appearance. Dull, phosphated porcelain is, on the contrary, less satisfactory; besides, the English have replaced it by a special body, which, when burnt, has a slightly yellowish colour, with a dull brilliancy, reminding one of the beautiful marble from Paros, whence its name of Parian.

The body is chiefly composed of a mixture of kaolin and feldspar; the latter, under the influence of the high temperature, becomes semi-fused, and this gives it a milky appearance. According to Prössel, the following are some examples of its composition :—

| | *Frit.* | | | |
|---|---|---|---|---|
| Kaolin . . . . . | 11 | — | — | — |
| Feldspar . . . . . | 25 | — | [illegible] | [illegible] |
| White sand . . . . | 58 | 83 | — | — |
| Potash . . . . . | 6 | 18 | [illegible] | [illegible] |

*Body.*

| | | | | |
|---|---|---|---|---|
| Frit | 15 | 9 | — | — |
| Kaolin | 39 | 28 | 33 | 37 |
| Feldspar | 39 | 42 | 44 | 63 |
| Pegmatite | — | 14 | 22 | — |
| Flint glass | 6 | 7 | — | — |

The body may be coloured in such a way as to give goods that imitate ivory or different natural stones, whence the names of carrara, malachite, lazulite, porphyry, obsidian.

The plasticity being so slight makes the moulding rather troublesome, therefore casting is often resorted to. The hard firing is done at the same temperature as for phosphated porcelain, but the great shrinkage, as well as the softening of the mass, necessitate the saggering being very carefully done by holding up the projecting parts by supports made of raw body.

### 7. *Dull Feldspathic Soft Porcelain.*

**306.** By this name are called some small objects, buttons, and imitations of pearl and agate. This manufacture was invented towards 1840 by Prosser. First he used the English soft porcelain body, then simply a mixture of feldspar and phosphate of lime, to which plasticity was given by the addition of a greasy body, which was destroyed when burnt.

M. Bapterosse introduced this industry into France, but employed special processes. Thanks to a very perfect machinery, he succeeded in entirely doing away with the English manufacture, and his factory at Briare, with another at Fribourg (in the Grand Duchy of Baden), are the only ones which manufacture this kind of ware at the present time.

On account of the very restricted interest in this manufacture, which is only allied to pottery by the methods employed, we will briefly summarise it.

The body is formed of feldspar, as fusible as possible, which is powdered and separated from a part of the impurities (oxide of iron) that it may contain, leaving in it the sulphuric acid. To it is added, according to what goods are wanted, some colouring oxides, or sometimes a little phosphate of lime or chalk. The powder, for want of plasticity, has some milk

added to it or an emulsion of caseine in a solution of boracic acid, so as to give it a consistency firm enough for it to be moulded in a press. Five hundred buttons are thus moulded with one stroke of the beam. They are arranged automatically on a sheet of paper, which is used to carry them on to a fire-proof plate. This is first heated, so that the paper is burnt up; then the plate is put into a muffle, where it remains for about ten minutes. It is then drawn out, the buttons that are on it are taken off with one stroke of a rake and it is covered with a fresh sheet of paper. The muffles are arranged to the number of thirty in a rectangular kiln with down draft. The burnt buttons fall into a series of boxes which are fastened to a pivot, where they finish cooling, and from which they are taken out through a movable bottom. Then they only need to be decorated, if that is required, with the help of vitrifiable colours by chromo-lithography, or to be gilded and then saggered. Latterly, they have also manufactured by this process cameos and small cubes, which are used in making mosaic floors.

THE END.

# INDEX.

## A.


Absorption, Defects in glaze due to excess of, of body, 316; drying by, 269-271.
Accidental impurities in natural clays, 56-57.
Actinometric pyrometer, Latarche's, 399.
Adhesion, Defects in glaze due to want of, 315-316.
Aeration, Drying by, 252-255.
Agglomerative materials for ceramic bodies, 70-71.
Agglutinative materials for ceramic bodies, 70-71.
Agreement of bodies and glazes, 316-320.
Air, Effect of the electricity of the, in plastic bodies, 107.
Alençon, Discovery of kaolin at, 37.
Alkalies in glazes, 274-275; in natural clays, 53; proportion of, in plastic bodies—*see* Lime, Magnesia.
Alkaline earths, Compound, as raw materials of glazes, 282-283; earthy bases of glazes, proportion of, 275.
— fluxes, 77-79; testing of, by chemical analysis, 98-99.
— salts as raw materials of glazes, 280-282; fumes of, in atmosphere of kilns, defects in bodies due to, 313.
Allophane, Composition of, according to Le Chatelier, 68; Vogt on, 69; where found pure, 69; dehydration point of, 88.
Alsing cylinder, described, 169-172; *illustrated*, 171.
Alum as a raw material of glazes, 282.
Alumina as a refractory element for clays, 83; forms of, 84-85; proportion of, in plastic bodies, 101; in glazes, 275; influence of, on fusibility of bodies, 303; influence of, on pure clay as affecting its fusibility, 574-575; mixtures of silica and, scale of fusing temperatures of, 575.
— Hydrosilicates of, dehydration point of, 88.
Aluminous fireclay goods. *See under* Fireclay goods.
America, Central, Archæological discoveries in, 16. *See also* Mexico.
American borax as a raw material of glazes, 280.
Amianthus, Use and analysis of, 70.
Amorphous silica, 71-72; formed from crystalline silica, 72.
Amphora, Manufacture of, 18.
Analysis of gases. *See* Gases.
Ancient earthenware—
Arabian: history of ceramics of early Empire, 21; Arabian faience ware in Sicily, 22.
Moresque: Hispano-Moresque faience, 21; its characteristics, 21; masterpieces of, 21; Christianising influences at work, 21; the Spanish Conquest and downfall of the industry, 22; the art inherited by Italy, 22.
Persian: perfection of monumental ware, 19-20; examples in the Louvre, 20; body employed, 20; glazes used, 20; traditions of Egyptian art maintained in, 20; effect of Arabian conquest on, 20; the art at Damascus and Rhodes, 22.
Ancient terra cotta, method of manufacture in Egypt and Assyria, 17; universal characteristics of first productions, 17; their purposes and shapes, 17-18; amphora, 18; Campanian ware, 18; Greek terra cotta, 18; process of slipping, 18-19; use of glaze, 19; Roman building pottery, 18-19.
Andreoli, Georgio, 24.
Annealing, 387.
Anthracite. *See* Coal.
Antimony as a colouring material for pottery, 413; oxide of, in glazes, 276.
Anti-plastic materials for ceramic bodies. *See under* Non-plastic.
Appert and Henrivaux, Definition of glass by, 272; definition of enamels by, 278.
Arabs, Introduction of art of faience into Europe by the, 21.
Architectural faience, Resistance of, to weather and frost, 610-611; varnished, 607-611; porcelain, 727; stoneware, 695-697; terra cottas, 542-545.
Argillaceous fireclay goods. *See under* Fireclay goods.
— soft porcelain, 735-736.
Arndt apparatus for analysing gases, 393.
Artaxerxes Mnemon, Monumental earthenware of the time of, 20.
Assyria, Chronicles of, on clay plaques, 15.
Assyrian pottery, 15.

Astbury, Use of silica powder discovered by, 31; method perfected by Josiah Wedgwood, 31.
Atmosphere of kilns, 388-391; defects in bodies due to wrong composition of, 312-313.
Ausbach ware, 30.
Austria. *See* Bohemia.
— Chief beds of refractory clays in, 62; of vitrifiable clays, 63; of kaolin, 60.

B.

Babylon, Discoveries in the ruins of, 15.
Bagnolet, First manufacture of hard porcelain at, 37.
Ball grinders for mechanical disaggregation, 123-124; described, 123; particulars of different models, 123; Dalbouze's grinder, described and *illustrated*, 123; the Morel mill, 123; the Carter mill, 123-124; the Cyclone disintegrator, 124.
Balling, Examples of analyses of clays by, 65.
Bamboo sugar, Use and composition of, 84.
Barbotine, 426-427.
Baryta in natural clays, 55; in glazes, 275; as a raw material of glazes, 283.
Basic fireclay goods. *See under* Fireclay goods.
Bastenaire, Composition of former glazes for pipeclay faiences by, 633.
Bastenaire-Daudenart, Compositions for the enamel of faience by, and Brongniart, 617.
Batt making explained, 216-217; *illustrated*, 217.
Bauxites as refractory materials, 84; where found, 84-85; analyses of, 85.
Beading, 422-423.
Beauvais, Early glazed vase industry at, 25; character of, pottery, 25. *See* Chapelle aux Pots, Savignies.
Belgium, Chief beds of refractory clays in, 62; of vitrifiable clays, 63; stanniferous ware factories of, 31.
Beni-Hassan, Discoveries in the tombs of the, 15.
Bentley, Thomas, and Josiah Wedgwood, 31.
Berettino, meaning of the term, 23.
Berthier, Examples of analyses of clays by, 65, 66.
Bidermann and Herzfeld on the causes of the plasticity of clay, 46.
Bischof and mistaken formula for pure clay, 45; examples of analyses of clays by, 65, 66; his comparative process to determine plasticity of clays, 95-96; results of tests on French clays with Fontainebleau sand, 96; results obtained with quartzy sand, 96-97; his method for testing fusibility of refractory clays, 97; his system of defining by number the fusibility of argillaceous fireclay goods, 576-577.
Biscuit, Definition of, 1; alternative terms, 1*n*.
— porcelain, 727-728.
Bismuth, Oxide of, in glazes, 276; as a raw material of glazes, 287.
Blacks, Preparation of, for pottery, 414-415; how obtained, 424.
Black tiles. *See under* Tiles.
Blade propellers. *See under* Propellers.
Blake, Johnson and, on the causes of the plasticity of clay, 46.
Blake grinders. *See* Chopping machines.
Blisters, Cause of, 316.
Blueing black tiles, 532-533.
Blues, Preparation of, for pottery, 415; how obtained, 424-425.
Blungers for pure clay, *illustrated*, 140, 142; for antiplastic materials, *illustrated*, 170, 171. *See* Blunging.
Blunging of antiplastic materials, Method of, 169-172; machines for, *illustrated*, 170, 171.
— of clay, 138-143; by hand, 139; hydraulic, 139; mechanical blungers, described and *illustrated*, 139-143; method adopted in Schmelzer's machine, 143.
— of pure clay, Method of, 168-169; machines for, *illustrated*, 140-142.
Bodies, Agreement of, and glazes, 316-320; influence of firing on volume and density of, 305-308; on colouring, 308-311; defects in, after firing, 312-315.
— Drying of. *See* Drying.
— Plastic. *See under* Plastic.
Bodies, Preparation of, 150-181:
By plastic method, 150, 151-163: apportionment of raw materials and of water, 151-152; homogeneisation of bodies, 152-153; grinding or rolling, 153-154; pugging, 154-160; rolling and pugging combined, 160; preparation of stiff body, 160-163.
By dry method, 151, 163-167: operations explained, 163-164, 165-167; Jannot pulveriser, described 164, *illustrated* 166.
By liquid method, 151, 167-181: methods of preparation, 167-168; blunging of raw materials, 168-172; apportionment and mixing in liquid state, 172-173; sifting, 173-174; stiffening, 174-181; pugging and wedging or slapping, 181.
*Illustrations:* Roller mill, 154; fluted roller mill, 155; vertical pugs, 156, 165, 180; plan showing bottom scraper, 156; horizontal pugs, 157, 158, 159; pug knives, 158; double horizontal pug, 160; vertical roller pug, 161; combined roller mixer and horizontal pug, 162; double roller mill, 163; roller granulators, 164; pulverizer, 166; levigating or grinding mill, 170; Alsing cylinder, 171; lawn or sieve for slip, 173; filter presses, 176, 177, 178, 179.
Body, meaning of the term, 1; alternative term, 1*n*; decorative moulding of, 421-423; colouring of, 423-426; preparation of, for feldspathic faiences, 639-641;

composition of, for hard porcelain, 702-707; preparation of, 708-709; colouring of, 720 *et seq.* *See* Hard bodies, Soft bodies.
Bohemia, greatest centre of hard porcelain production in Austria, 42.
Bonding tile, Gilardoni the inventor of the, 40.
Bonn. *See* Siegburg.
Boracic acid in glazes, 274; as a raw material of glazes, 279-280; refined, 279; Tuscany, 279-280.
Borax, Refined and American, as raw materials of glazes, 280.
Bordier centrifugal grinder, 122; particulars of four types, 122.
Borie, inventor of tool for manufacture of hollow bricks, 39.
Böttcher, biographical notes, 35-36; discovery of secret of porcelain manufacture by, 35-36.
Bottle glass, White, as a raw material of glazes, 279; limits of variation in composition of, 279.
Boulet et Cie on capabilities of cutters, 130; grinder with plain rollers, *illustrated*, 128; circularly fluted rolling machine, *illustrated*, 154; conic form of rolling machine, *illustrated*, 155; rolling machine for stiff bodies, described 161, *illustrated* 163; vertical pug mill for stiff bodies, 165.
Boulton, Potter's cone drum wheel by, described, 188-189; *illustrated*, 188.
Bourgerel, Graphic method of, to determine proportions of raw materials for a given plastic composition (*illustrated*), 102-103.
Bourry, Examples of analyses of clays by, 67.
Bradwell stoneware factory, 33; influence of, 33.
Breteuil halloysite, Analysis of, 68.
Brethon hydraulic purifier with screw propeller, described, 136-137; *illustrated*, 137.
Brewer & Co., Purifying machine by, described and *illustrated*, 132-133.
Brick for continuous regenerator, *illustrated*, 379.
Bricks, 447-503:
Plain ordinary, 448-492: forms and dimensions, 448-450; moulding by hand, 450-452; moulding by machine, 452-453; manufacture by expression, 453-462; manufacture with a press, 462-468; repressing, 468-475; drying, 475-482; burning, 482-490; general arrangements of brickfields, 490-492.
Hollow, 492-494.
Ornamental, 494-499.
Vitrified, 499-501.
Light, 501-503.
— Mechanical causes of disaggregation of, 557.
Brickfields, General arrangements of, 490-492.
Brick press, Quadruple, described, 230-231; *illustrated*, 230.
Brongniart, New term suggested by, 1*n*; system of classification of, 7-9; criticised, 8-9; "Treatise on the Ceramic Arts" by, 7; on amphora, 18; on glaze, 19; his estimate of Palissy, 26; and mistaken formula for pure clay, 45; analyses of halloysite and lenzenite by, 68; of collyrite, 69; on ancient lustre ware, 553; composition of the body of a number of enamelled faiences by, 616; compositions for the enamel by, and Bastenaire-Daudenart, 617.
Brown, Examples of analyses of clays by, 66.
Browns, Preparation of, for pottery, 417; how obtained, 425-426.
Bruges porcelain factories, 31.
Bubbles, Cause of, 316.
Burning of argillaceous fireclay goods, 584-585; of plain ordinary bricks, 482-490; of colours, 442-443; of feldspathic faiences, 650-652; of hard porcelain, 715-718; of ordinary tiles, 525-528; and salting of stoneware pipes, 687-690.
Burslem factories, 31.

## C.

Caffaggiolo majolica, 24.
Calcareous fluxes, 79, 82; stones in natural clays, 57.
Calcareous clayey bodies, Influence of firing on volume and density of, 308.
Campanian ware, 18.
Cantharides lustre, 438.
Carbonate of iron in natural clays, 54.
— of lime in natural clays, 54, 56; use of, as a flux, 79.
— of magnesia in natural clays, 54, 56.
Carbonic acid, Proportion of, in plastic bodies, 101.
Carboniferous fireclay goods. *See under* Fireclay goods.
Carr disintegrator, described and *illustrated*, 120-121; different models of, 121.
Carrara porcelain, 42.
Carter mill, 123-124.
Carving, 233.
Castel-Durante majolica, 24.
Castelli majolica, 24.
Casting, Moulding by, 231-232.
Cat's hole tiles, 510.
Cement, Difference between ceramic ware, glass and, 3.
Centrifugal grinders for mechanical disintegration, 120-122: principle and use of, 120; the Carr disintegrator described and *illustrated*, 120-121; different models of, 121; Weidknecht-Schoeller's "Loizeau" grinder, 121-122; different patterns of, 122; Bordier's grinder, 122; particulars of four types of, 122.
Ceramics, Phraseology of, 1*n*; wide importance of, 2; use of glaze in, 2; the study of, 3-4; history of, 14-43. *See* History of ceramics.
Ceramic bodies, Materials forming, 44-85: clays, 44-67; various raw materials, 67-85. *See* Clays, Raw materials.

Ceramic ware, General classification of, 2; definition of, 3; difference between glass, cement and, 3; non-clay wares included under, 3; technical classification of, 4; general principles of classification of, 4-6; distinctive characteristics of, 5-6; first attempts at classification of, 6-7; classification of, by Brongniart, 7-9; by Salvetat, 9-10; by Knapp, 10; by Kolbe, 10-11; by Bruno Kerl, 11-12; true division of, 12; sub-divisions, 13-14; and table, 14. *See* Classification.
Chaffers, founder of English soft porcelain industry, 37.
Chaldea, Chronicles of, on clay plaques, 15.
Chaldean pottery, 15.
Chamber Bros. & Co., Granulator of, described 130, *illustrated* 131; mill with movable slab by, described and *illustrated*, 126-127.
Chambrette, Purifier of, described 134-135, *illustrated* 134; hydraulic purifier of, described 135, *illustrated* 136.
Channel kilns, described, 370-372; for heating with faggots, *illustrated*, 369; for heating with coal, *illustrated*, 370.
Chantilly, Soft and hard porcelain factories at, 37.
Chapelle-aux-Pots, La, early glazed vase industry, 25; stoneware, 33.
Charging, 383-386; the kiln itself, 383-384; with quarries or slabs, described and *illustrated*, 384; in saggers, 384-386; saggers *illustrated*, 385; defects in bodies due to bad, 312.
Charlotte, Queen, and patronage of Burslem ware, 31.
Chelsea, Establishment of soft porcelain manufacture at, 37.
Chemical composition of glazes, 274-276.
— productions, Stoneware for, 692-695.
purifying of raw materials, 148-149.
Chemistry as a basis of classification, 6, 7.
Chicaneau and the discovery of soft porcelain, 37.
Chimneys in kilns, 345-348; laws relating to, 347-348; table showing depression, volume and weight of air per second given by a chimney of stated dimensions at increasing temperatures, 348; substitutes for, 348.
China a birthplace of ceramics, 16; of impermeable pottery, stoneware and china, 16; chief beds of kaolin in, 60.
China, Definition of, 14; a synonym of porcelain, 10.
Chinese porcelain, Revolution caused by introduction of, 6-7.
Chintho - Kang - Hu, Characteristics of Chinese porcelain under, 34.
Chjzek, Examples of analysis of clays by, 66.
Chopping machines or Blake grinders for mechanical disaggregation, 123 - 124; described and *illustrated*, 124; particulars of various models, 124-125.
Chromium in natural clays, 56; as a colouring material for pottery, 410-411.
Chronicles of Chaldea and Assyria on clay plaques, 15.
Church and the classification of Wedgwood wares, 32.
Cimolite, Composition of, 69; where found, 69; use of, 69; analysis of, by Klaproth, 69.
Classification, Difficulties of, 4-5; true method of, 5-6, 12-14; first attempts at, 6-7; chemistry as a basis of, 6, 7; Brongniart's method of, 7-9. *See* Ceramic ware.
Clay, Materials analogous to, 68-70. *See* Allophane, Amianthus, Collyrite, Cimolite, Giobertite, Halloysite, Lenzenite, Magnesite, Marls, Steatite, Talc.
— Calcined and plastic, as raw materials of glazes, 279.
Clays, Definition of, 1; the basis of ceramic productions, 3.
Pure Clay, Composition and chemical properties of, 44-46; physical properties of, 46-48; formation of, 48-50.
Natural Clays, Formation of, 50-52; materials composing, 52-57: materials not separable by grinding, 53-56; materials separable by grinding, 56; accidental impurities, 56-57.
Classification of, 57-59: kaolins, 59-60; refractory clays, 60-62; vitrifiable clays, 62-63; fusible clays, 63-64. *See under* Fusible, Kaolin, Refractory, Vitrifiable.
Table of analyses of, 64-67.
Trials of, 85-97: methods of trial, 85; trials on the constitution of, 86-88; chemical analysis, 88-90; special estimation, 90-92; tests of the texture, 92-95; tests as to plasticity, 95-97; tests on the fusibility, 97.
Clayey bodies, Influence of firing on volume and density of, 307-308; of those containing quartz, 308; of calcareous clayey bodies, 308.
— pottery, System of classification of, 10-11.
Clérissy family, founders of the Moustiers school, 28.
Cloisonné enamel, 431.
Coal as a fuel, 326-327; heating by, 332-338.
Cobalt as a colouring material for pottery, 411-412.
Coke as a fuel, 327.
Cold decoration, 441-442.
Collyrite, Composition of, according to Le Chatelier, 68; where extracted, 69; analysis of, by Brongniart, 69; dehydration point of, 88.
Colour as a basis for measuring temperature of kiln, 394-395; results obtained by Pouillot, 395.
Colours, Burning of, 442-443; composition of, for silicious faiences by Deck, 628-630; for feldspathic faiences, 656-658.
Coloured glazes, 430-431.
— slips, 426-427.

Colouring, Influence of firing on, of bodies, 308-311.
— materials used in pottery, methods of application, 407-408; how the colouring is influenced, 408-409; preparation of, 414-417; properties of, 417-420.
— metals, 409-414.
— of body, 423-426; under glaze, 427-430; over glaze, 431-435; of hard porcelain, 720 *et seq.*
Common faience, meaning of term, 8, 9; pottery, 547-549; varnished faiences, plumbiferous 602-605, non-plumbiferous 605-606.
Composition of glazes, 272-276; defects in glaze due to errors in, 316.
Compound alkaline earths as raw materials of glazes, 282-283.
Compressing moulds. *See under* Moulds.
Conrade Brothers and Nevers faience, 26-27; their successors, 27.
Consistency, Influence of, on drying of bodies, 243-245.
— of plastic bodies, 107-108: classification of bodies as a basis of, 107; method of estimating, by the touch, 107; exact method of measurement of, 107-108; quantity of water required to obtain different degrees of, 108.
Constantin on composition of glazes for common non-plumbiferous varnished faience, 605, 606.
Construction of kilns, 380-383.
Contemporary ceramics, 38-42: nineteenth century influences, 38; growth in importance of terra cotta, 38-39; introduction of mechanical presses and firing at high temperature for brick making, 39; invention of Borie's tool for manufacture of hollow bricks, 39; invention of bonding and South of France tiles, of drainage pipes, and of refractory ware, 40; German scientific researches, 40; extension of English stoneware, ironstone and opaque porcelain to Continent and America, 40-41; revival of stanniferous and ancient Persian faience, 41; Messrs. Doulton & Co.'s works, 41-42.
Continuous kilns with single firing chamber, described 363-365, 367-372, *illustrated* 366, 367, 368, 369, 370; with several firing chambers, described 372-375, *illustrated* 373, 374.
Contraction, Agreement of bodies and glazes in respect of, during cooling, 317-320; importance of the problem, 317-318; its solution, 318-319.
Cooling of ware, 401-402; defects in bodies due to rapidity in, 312.
Copper in natural clays, 56; as a colouring material for pottery, 410; lustres, 438.
Coquillon apparatus for analysis of gases, described, 391-392; *illustrated*, 392.
Cornish-stone as a raw material of glazes, 279.
Crackling, Cause of, 317; remedy for, 318; as a means of decoration, 438-439.
Crayons, Vitrifiable, for decorating pottery, 441.
Crazing, Cause of, 317; remedy for, 318, 319; action of silica in respect of, 318-319; action of fluxes, 319.
Cryolite as a raw material of glazes, 286-287.
Crystal as a raw material of glazes, 279; limits of variation in composition of, 279.
Crystalline silica, 71; forms of, 71; transformation of, into amorphous silica, 72. *See* Quartz, Silex.
Custade family and Nevers faience, 27.
Cutters for mechanical disaggregation, 129-130: use and description of, 129-130; capabilities of, according to Boulet et Cie, 130.
Cutting apparatus, described, 204-206; *illustrated*, 205.
Cyclone disintegrator, The, 124.
Cylindrical propellers. *See under* Propellers.

## D.

Dalbouze grinder, described and *illustrated*, 123.
Damascus, Brilliant period of Persian art at, 22.
Darcel on characteristics of Hispano-Moresque faience, 21; on Nevers faience, 27; on characteristics of Rouen style, 27.
Darius, Monumental earthenware of the time of, 20.
Decanting tanks, Use of, 144-147.
Deck, Criticism by, of Brongniart's system of classification, 8-9; definition of faience by, 9; on Rouen style, 27-28; reproduction of celebrated turquoise blue Persian faience by, 41; attempts of, to reproduce Persian faiences, 626-627.
Decoration, 407-443:
Colouring materials, 407-420: general remarks, 407-409; colouring metals, 409-414; preparation of, 414-417; properties of, 417-420.
Processes of decoration, 420-443: general remarks, 420-421; decorative moulding of body, 421-423; colouring of body, 423-426; coloured slips, 426-427; under glaze colouring, 427-430; coloured glazes, 430-431; over glaze colouring, 431-435; decoration with metals, 435-436; decoration with metallic lustres, 436-438; other methods, 438-442; burning the colours, 442-443.
Decoration, Cold, 441-442.
— of feldspathic faiences, 655-658; of hard porcelain, 720-723.
— Porcelain for. *See under* Porcelain.
Decorative moulding of body, 421-423.
— objects, 545-547; in varnished faiences, 613-615; stoneware, 697-698.
Defects in bodies after firing, 312-315; presented by glaze from non-adhesion 315-316, from body being too absorbent 316, from too low or too high temperature in burning 316, from errors in composition 316.

Delahaye hydraulic purifier with screw propeller, described, 136-137; *illustrated*, 137.
Delft school, History and characteristics of, 30.
Dense pottery, 10.
Density, Influence of firing on, of bodies, 305-308.
Deruta majolica, 24.
De Smet et Cie, Tiles manufactured at highest pressure by, 106*n*.
Deux-Sèvres. *See* Saint-Porchaire.
Dicing, 423*n*.
Dies for expression, described, 195-198; *illustrated*, 195, 196, 197; roller dies, *illustrated*, 204.
Diffusion, Application of glazes by, 298.
Dipping, Application of glazes by, 295-297.
Disaggregation, Object of, 111; classification with a view to, 111.
— Processes of, 111:
Natural, 111-113: applicability of, 111-112; methods of, according to climate, 112-113; warehousing of clay, 113.
By heat, 113-118: processes for, 114; Lecaze stove for disaggregating large productions (*illustrated*), 114-115; Schmidt & Co.'s stove (*illustrated*), 115-116; method in use for quartz, silex and feldspar, 116-117; use of reverberating kilns, 117; use of sliding kilns, 117; furnace for disintegration of flint (*illustrated*), 117-118.
Mechanical, 111, 118-130: classification of machines according to mode of action, 111; stampers (*q.v.*), 118-120; centrifugal grinders (*q.v.*), 120-122; ball grinders (*q.v.*), 123-124; chopping machines (*q.v.*), 124-125; vertical mills (*q.v.*), 125-127; rolling grinders (*q.v.*), 127-129; cutters (*q.v.*), 129-130; granulators (*q.v.*), 130.
— of raw materials. *See under* Raw materials.
— of terra cotta, Causes of, 554 *et seq.*; remedies for, 555 *et seq.*
Dishes, Varnished faience, 613-615.
Distilled water, Use of, 90.
Doulton & Co., Works of, at Lambeth, 34.
Draught, Forced, use of, in kilns, 348; measuring the, 393-394; apparatus for, described and *illustrated*, 394. *See also under* Firing.
Drying, Theory of, 238-241; influence of the nature of the body 241-243, of the consistency 243-245, of the method of formation 245-246, of the shape of the objects 246-247; rules for making of models, 247; influence of the rapidity of drying, 247-248; by evaporation, 248-252; by aeration, 252-255; by heating, 255-256; by ventilation, 256-258; by heated and aerated dryers, 258-260; by dryers heated and ventilated with fixed shelves, 260-264; by dryers heated and ventilated with movable shelves, 264-269; by absorption, 269-271.
Drying (*continued*)—
*Illustrations*: Diagrams of drying 241, of drying of different bodies 242, of influence of consistency upon shrinkage and pores 244, and upon duration of drying 245; evaporometer, 252; dryers, 253, 254; ventilating fan, 257; dryers heated and aerated, 259; heated and ventilated, with fixed shelves, 260, 261, 262-264; with movable shelves, 264, 265, 268; revolving, 262; tunnel, 263.
— of argillaceous fireclay goods, 583; of feldspathic faiences, 647-650; of hard porcelain, 714-715; of ordinary tiles, 524-525.
— of plain ordinary bricks in the open air, 475-476; on stages, 476-480; in ventilated sheds, 480-481; in warmed ventilated sheds, 481-482.
Dull or biscuit porcelain, 727-728; soft porcelain, 736-737; feldspathic soft porcelain, 737-738.
Dumont granulating rolling machine, described, 161-162; *illustrated*, 164.
Durantino, Guido, and Urbino majolica, 23.
Dust tiles, Encaustic, 679.
Dusting, Application of glazes by, 298.
Dutch faience: the Delft factories and school, 30; three periods of manufacture and characteristics, 30.
Dwight, John, founder of Fulham stoneware factory, 33.

## E.

Earthenware, Synonym of, 1; substitutes for the term, 7; definition of, 13.
Eggshell, Cause of, 316.
Egypt a birthplace of ceramics, 14-15, 16-17; archæological discoveries in, 15; coloured enamels used in, 19; art of faience in, destroyed by Roman conquest, 20.
Eichhorn, Examples of analyses of clays by, 66.
Electric purifying of raw materials, explained and *illustrated*, 147-148.
— pyrometer, Siemens', 399; Le Chatelier's thermo-, 399-400.
Electrical conduits, Porcelain for, 725.
— purifier for the manufacture of glazes, described, 294-295; *illustrated*, 296.
Elers, The Brothers, founders of Bradwell stoneware factory, 33.
Emptying, 402.
Enamel, Painting for hard firing on raw, 618; on burnt, 618-619.
— Cloisonné, 431.
Enamels, Definition of, 277; by Appert and Henrivaux, 278; reason of Greek dislike for, 20-21; neglect of, by Romans, 20-21.
Enamelled faiences, Composition of the body of a number of, by Brongniart, 616; compositions for the enamel by Brongniart and Bastenaire-Daudenart, 617. *And see under* Faiences.
Encaustic dust tiles, 679.

Encaustic tiles, Varnished faience, 611-613.
Engine turning, 423.
England, Influence of, on French art, 29.
English faience, early foreign importations, 31; Dutch factory at Lambeth, 31; Burslem factories, 31; discovery by Astbury of use of silica powder, 31; perfected by Josiah Wedgwood, 31; importance of Leeds manufactures, 31; Queen's ware, 31; association of Wedgwood and Thomas Bentley, 31; imitation of the antique, 31-32; classification of Wedgwood wares, 32; stanniferous faience, 32; porcelain, 32.
— porcelain, 728-730.
European porcelain, Early failures at reproduction of Chinese porcelain, 35; Böttcher's discovery of the secret, 35-36; establishment of first workshops at Meissen, 36; spread of the industry, 36; discovery of soft porcelain by Chicaneau, 37; spread of the industry, 37; Sèvres factory founded, 37; discovery of Saint-Yrieix kaolin deposits by Mme Darnet, 37; consequent abandonment of soft porcelain and supremacy of hard porcelain in France, 37; manufacture of soft and hard porcelain in England, 37-38.
Evaporation, Use of, in ascertaining constitution of clay, 87-88; drying by, 248-252.
Evaporometer, Use of, 251-252; *illustrated*, 252.
Excentric press, *illustrated*, 228; tile press, described 230, *illustrated* 229.
Excipient, suggested new term, 1*n*.
Expression, 195-206: dies, described 195-198, *illustrated* 195, 196, 197; propellers, described 198-204, *illustrated* 198, 199, 200, 201, 202, 204; cutting apparatus, described 204-206, *illustrated* 205; manufacture of plain ordinary bricks by, 453-462; of ordinary tiles, 512-516.

## F.

Faenza, Majolica wares of, 23.
Faience, derivation of the word, 23; synonym of earthenware, 1; misuse of the term, 7, 9; definition by Deck, 9; art of, in Egypt destroyed by Roman conquest, 20; introduced into Europe, 21.
Faiences, 598-659:
Classification, 598-602.
Varnished, with fusible argillaceous body, 602-615: common plumbiferous ware, 602-605; common non-plumbiferous ware, 605-606; architectural faiences, 607-611; encaustic tiles, 611-613; stoves, 613; vases, dishes and decorative objects, 613-615.
Enamelled, with fusible argillaceous calcareous body, 615-624: composition, 615-618; decoration, 618-619; stove tiles, panels, etc., 619-624.
Silicious, with fusible silicious body, 624-631.
Faiences (*continued*)—
Pipeclay, with slightly fusible argillaceous calcareous body, 631-635.
Pebble work, with fireproof argillaceous silicious body, 635.
Feldspathic, with slightly fusible argillaceous alkaline body, 636-658: composition, 636-639; preparation of the bodies, 639-641; moulding, 641-647; drying, 647-650; burning, 650-652; setting and placing in saggers, 652-655; decoration, 655-658.
General arrangements of faience works, 659.
*Illustrations:* Moulding of stove tiles, 621, 622; machine for same, 623; lathe for making batts, 641; wheel for moulding flat ware, 642; wheel for making and moulding shapes, 643; double wheel for moulding flat articles, 644; jolley for moulding cups, bowls, etc., 644; jolley for moulding large hollow pieces, 645; pulverising machine, 646; press for moulding paving tiles, 647; kilns for earthenware, 648, 649; methods of filling the saggers, 652, 653, 654, 655.
Faience works, General arrangements of, 659.
Feldspars in natural clays, 53, 56; use of, as fluxes, 78; chief beds of, 78; table showing composition of different, 80-81; testing of feldspar fluxes by chemical analysis, 98; method of disaggregation in use for, 116-117; as raw materials of glazes, 278-279.
Feldspathic faiences. *See under* Faiences.
— rocks, Use of, as fluxes, 78; pegmatite, 78-79; Cornish-stone, 79; analogous rocks, 79; table showing the chemical composition of different feldspars and, 80-81.
— soft porcelain, Dull, 737-738.
Ferrara majolica, 24.
Ferric fluxes, 82.
Ferrous oxide, Influence of, on fusibility of bodies, 303-304.
Figuring, 235.
Filters, 549-550.
Filter presses, Use of, in connection with settling tanks, 146; first, for stiffening, described 175-176, *illustrated* 176; present type, described 176, *illustrated* 177; Leclaire's, described 177-178, *illustrated* 177; French and German types, described and *illustrated*, 178; English type, described 178, *illustrated* 179; volume of body stiffened by different sizes of press, 179; method of calculating same, 179; the working of the press, explained 180-181, *illustrated* 180.
Fine faience, use of the term, 9.
— stoneware, 698-699.
Finishing, 232-235: object of, 232-233; manual operations of, explained 233-235, *illustrated* 234, 235.
Fire, Porcelain for the, 724-725.
Fireclay, Use of mixture of, and fluxes for paving tiles, 667-668.

Fireclay goods, 568-597:
Classification, 568-570.
Argillaceous, 570-586: shapes, dimensions and properties, 570-574; resistance of fireclay to high temperatures, 574-577; composition and preparation of the body, 578-579; moulding, 579-583; drying, 583; burning, 584-585; general arrangements of the manufactories for fireclay goods, 585-586.
Aluminous, 586-588.
Carboniferous, 588-590.
Silicious, 590-592.
Basic, 592-595: with magnesia, 593-594; with magnesia and lime, 594-595; with lime, 595.
Fireclay mortar (pug), 595-596.
Tests, 596-597.
*Illustrations:* Fireclay goods, 572; scale of fusing temperatures of mixtures of silica and alumina, 575; moulding by hand of crucible for glass making, 581; moulding of gas retort by hand, 581; machine for moulding saggers, 582; machine for moulding crucibles, 589.
Fireclay mortar, 595-596.
— terra cottas, Chemical classification of, 569.
Fired refractory bodies, 13.
Fireplaces. *See under* Firing.
Fireproof materials, Use of mixture of, and fusible clays for paving tiles, 666-667.
Firing, 299-406:
Properties of the bodies and glazes during the firing, 299-322; general remarks on firing, 299-300; modifications in the constitution of the bodies, 300-303; the part played by the different materials constituting the bodies with regard to their fusibility, 303-305; modifications in the volume and the density, 305-308; modifications in the colouring, 308-311; defects in the bodies after firing, 312-315; firing of the glazes, 315-316; agreement between the bodies and the glazes, 316-320; experiments in fusibility and in firing, 320-322.
Description of the kilns, 322-383:
General remarks on kilns, 322-324.
Fireplaces, 324-345: fuel, 324-328; classification of the fireplaces, 328-330; heating by wood, 330-332; heating by coal with fireplaces formed of the ware 332-333, with fireplaces with gratings 333-335, with furnace fireplaces, 335-8; heating by gas, 338-345.
The Draught, 345-352: chimneys, 345-348; the draught in the kilns, 349-351; regulation of the draught, 351-352.
Kilns, 353-378: classification of kilns, 353; intermittent kilns with up draught 354-356, with down draught 356-363; horizontal intermittent kilns with single furnace, 363; continuous kilns with single firing chamber 363-372, with several firing chambers 372-
Firing (*continued*)—
Description of the kilns (*continued*)—
375; horizontal intermittent kilns with several fireplaces, 375-376; muffle kilns, 376-378.
Regenerators, 378-380.
Construction of kilns, 380-383.
Working of the kilns, 383-406: general remarks, 383; charging, 383-386; smoking, 386-387; firing properly so called, 387-388; the atmosphere of the kilns, 388-391; analysis of the gases, 391-393; measuring the draught, 393-394; measuring the temperature, 394-401; cooling and emptying, 401-402; thermic yield of the kilns, 402-406.
*Illustrations:* Variations of the volume of the bodies in baking, 307; trial kiln, 320; test kiln, 321; heating by wood, 331; wood fireplace, 332; heating by coal, 333; fireplaces with grates, 334, 335; furnace fireplaces, 336; kiln fireplaces, 337, 338; gas generator for sandy fuel 341, for fat fuel 342; blast gas generators, 343, 344; square kiln with up draught, 354; round kiln with up draught, 355; rectangular kiln with down draught, 357; round kiln with down draught 359, with an upper dome 360, with a lower dome 362; types of horizontal intermittent kilns with single furnace, 363, 364; kilns with continuous firing, 366, 367, 368; gas heating for kilns with continuous firing, 368; kiln with channels for faggot heating 369, for heating with coal 370; kilns with several burning chambers or spaces, 373, 374; semi-continuous kiln, 375; muffle kilns, 376, 377; brick for a continuous regenerator, 379; continuous regenerator, 380; charging with quarries or slabs, 384; saggers, 385; apparatus for analysing gases 392, for measuring draught 394; pyrometric tests, 398; pyrometric telescope, 400; optical pyrometer, 401.
Fischer, Examples of analyses of clays by, 66, 67.
Flamed decoration, 439.
Flammes, Origin of, 34.
Flaxman, Models for Wedgwood wares by, 32.
Flemish stoneware a misnomer, 33.
Flint, Furnace for disintegration of (*illustrated*), 117-118.
Flowing colours as a means of decoration, 439-440.
Flues, Use of, for drying, 256-257.
Fluorine in natural clays, 55; as a raw material of glazes, 286-287.
Fluorspar as a raw material of glazes, 286-287.
Fontainebleau sand the standard in France for determining plasticity of clays, 96.
Fontana, Orazio, and Urbino majolica, 23, 24.

Food, Stoneware for purposes of, 692-695.
Forbes and titanic acid in a natural clay, 56.
Formation, meaning of the term, 182; processes of, explained, 182-184: throwing, 184-194; expression, 195-206; moulding by hand 206-212, on the jolley 212-220, by compression 220-231, by slip casting 231-232; finishing, 232-235; slipping, 235-237; influence of method of, on drying of bodies, 245-246.
Forschammer and the true formula for pure clay, 46.
Francis I. and patronage of Italian ceramists, 25.
Franco, Battista, and Urbino majolica, 24.
Frankenthal ware, 30; porcelain works, 36.
Frechen, Stoneware factory of, 32; characteristics of its ware, 32-33.
Frederick Augustus II., Relations of, with Böttcher, 35-36; founder of Meissen workshops, 36.
French faience, 24-29: use of plumbiferous glaze in, 24-25; early factories for making of glazed vases, 25; decline of art glazed ware, 25; domestic glazed ware, 25; Italian ceramists and factories in France, 25; first purely French productions, 25; influence of Bernard Palissy on French art, 25-26; influence of Nevers faience, 26-27; beauty and characteristics of Rouen style, 27; its influence abroad, 28; the Moustiers school, 28; the Strassburg centre, 28; stanniferous enamelled faience at end of 18th century, 28-29; causes of its decline, 29.
— porcelain, 731-732.
Frits, meaning of the term, 77; use of, as fluxes, 78.
Fritting as an operation in the manufacture of glazes, 289-292.
Frytom, Frederick van, and Delft, 30.
Fulham factories, 31; stoneware factory at, 33.
Full fire, 387.
Fusibility of bodies, Influence of different materials on, 303-305; experiments in, 320-322.
— of clays, manner of determining, 97; Bischof's method for refractory clays, 97.
Fusible clays, 63-64: plastic ferruginous, 64; plastic calcareous, 64; silicious ferruginous, 64; silicious calcareous, 64; examples of analyses of different, 66-67; use of mixture of, and fireproof materials for paving tiles, 666-667.
Fusible materials for ceramic bodies, use and nomenclature, 77; alkaline fluxes, 77-79; calcareous fluxes, 79, 82; magnesic fluxes, 82; ferric fluxes, 82; phosphocalcareous fluxes, 82; influence of fluxes on fusibility of bodies, 303-304; action of fluxes in respect of scaling and crazing, 319; from the point of view of fusibility, 575-576; use of mixture of fluxes and fireclay for paving tiles, 667-668; composition of principal fluxes for hard porcelain, 722-723.

## G.

Gaize, Composition and use of, 84.
Galena as a raw material of glazes, 285.
Gannister, where found, 84; composition and use of, 84.
Garnier on stanniferous enamelled faience at close of 18th century, 28-29; causes of its decline, 29; on Nevers faience, 27; on Moustiers school, 28; on Strassburg faience, 28; on Hirschvogel and Nuremberg faience, 29.
Gas channels, Pipes for, 537-541.
— generators, Use of, 329-330; fuel for, 330; with natural draught, 340-342; blast, 342-344.
Gas, Heating by, 338-345; for kiln with continuous firing, described 368-372, *illustrated* 368.
Gases, Natural, as fuel, 327-328; analysis of, 391-393; Coquillon apparatus for same, described 391-392, *illustrated* 392; Meslans apparatus, 393; Arndt apparatus, 393.
German faience at close of Middle Ages, 29; Hirschvogel and the Nuremberg school, 29-30; other manufacturing centres, 30.
Gilardoni and the invention of the bonding tile, 40; system of tiles by, 507-508.
Giobertite, Composition and use of, 70.
Glass, Difference between ceramic ware, cement and, 3; kind of, included among ceramic ware, 3; use of, as a flux, 78; definition of, by Appert and Henrivaux, 272; glasses as raw materials of glazes, 279; limits of variation in their composition, 279.
— White bottle and window, as raw materials of glazes, 279; limits of variation in composition of, 279.
"Glass and Glassworks," by Appert and Henrivaux, quoted, 272, 278.
Glaze, Use of, 2; invention of art of covering fired bodies with, 16-17; composition and properties of glazes, 272-278; raw materials, 278-287; manufacture, 287-295; grinding machines, described 293-294, *illustrated* 293, 294, 295; application, 295-298; firing, 315-316; defects presented by glazes, 315-316; agreement of, and bodies, 316-320; under glaze colouring, 427-430; over glaze colouring, 431-435; coloured glazes, 430-431; for silicious faiences, composition of, 630-631; composition of glazes for pipeclay faiences, 633-634; for feldspathic faiences, 638-639; for hard porcelain, 707-708; their application, 714-715.
Glazes defined, hard, 277-278; soft, 277 transparent, 277.
— Vitrified, for faiences, analyses of, 623-624.
Global chemical analysis of clay, 88-90.
Gold in natural clays, 56; in Philadelphia clay, 56; as a colouring material for pottery, 413; use of, in metallic state for decorating pottery, 435-436; lustres, 437-438.

Granulators for mechanical disaggregation, Object of, 130; Chambers type, described 130, *illustrated* 131.
Grasses as fuel, 327.
Gravel as a non-plastic material, 72; as a refractory material, 83.
Greek fired bodies, wide meaning of the term, 18.
Greeks, Influence of, on ceramics, 16; perfection of plastic art of, 18; inventors of slipping process, 18-19; application of glaze by, 19; decline of art, 19.
Green ware, Definition of, 1; alternative terms, 1, *n.*
Greens, Preparation of, for pottery, 415-416; how obtained, 425.
Grentzhausen, Famous stoneware of, 33.
Greys, Preparation of, for pottery, 415; how obtained, 424.
Grinders, described, 169; *illustrated*, 170. *See also under* Ball, Blake, Centrifugal, Rolling.
Grinding, Materials not separable by, in natural clays, 53-56; separable materials, 56; not a method of analysis, 86; a means to determine texture of clay, 86; in water as a process in the manufacture of glazes, 292-295.
Grit. *See* Grog.
Grog, Nature of, 75; advantage in use of, 76; method of manufacture of, 76; as a raw material of glazes, 279.
Groke purifier, described and *illustrated*, 135.
Grooving, 233.
Grossalmerode white clay, Peculiarity of, 55.
Gubbio majolica and its leading artist, 24.
Guettard, discoverer of kaolin at Alençon, 37; first attempts at manufacture of hard porcelain, 37.
Guido Ubaldo II., Duke, influence on Urbino majolica art work, 23.
Guild of St. Luke and the invention of Delft ware, 30.
Gypsum in natural clays, 57; as a raw material of glazes, 282.

## H.

Halloysite, 68; analyses of, by Brongniart and Bruno Kerl, 68; analysis of Breteuil, 68; use of, 68.
Hambly, Examples of analyses of clays by, 65.
Handling, *illustrated*, 235.
Hannong, founder of Strassburg faience, 28; porcelain factories founded by, 36; sells secret of hard porcelain to Sèvres, 37.
Hard bodies, Brongniart's use of the term, 8; glazes, definition of, 277-278; porcelain—*see under* Porcelain.
Hautefeuille and the true formula for pure clay, 46.
Heat, Disaggregation by. *See under* Disaggregation.
Heating, Drying by, 255-256; defects in bodies due to rapidity in, 312.
Henri Deux faience, Origin of, 25; its influence on French ceramics, 25.
Henrivaux and Appert, Definition of glass by, 272; of enamels, 278.
Henry, Examples of analyses of clays by, 65.
Herzfeld, Bidermann and, on the causes of the plasticity of clay, 46.
Hirschvogel, Augustine, Influence of, on German faience, 29; Garnier on, 29; and the introduction of enamelled faience stoves, 613.
History of ceramics, 14-43: ancient terra cotta, 17-19; ancient earthenware (Persian, Arabian and Moresque), 19-22; Italian faience works, 22-24; French faience, 24-29; German, Dutch and various faience, 29-31; English faience, 31-32; stoneware, 32-34; Oriental porcelain, 34-35; European porcelain, 35-38; contemporary ceramics, 38-43.
Hoechst on the Mein ware, 30; secret of porcelain manufacture acquired for, 36.
Hoehr, Famous stoneware of, 33.
Hollow bricks. *See under* Bricks.
Homogeneisation of soft bodies, Operations for, 152-153; of stiff body, 161. *See* Pugging, Rolling mills.
Horizontal intermittent kilns with single furnace, described 363, *illustrated* 363, 364; with several fireplaces, 375-376.
Hydrate of alumina, its presence in natural clays doubtful, 55.
Hygrometric water, Use of, 90.

## I.

Immersion, Application of glazes by, 295-297.
Impermeable pottery, 11, 12-13; secondary characteristics of, 12-13; classes, is divided into, 14; discovery of, by Chinese, 16.
Impregnation, Colouring by, 423.
Impurities, Accidental, in natural clays, 56-57.
India, Early mention of pottery in the Vedas of, 15-16.
Infusorial clay, Composition and origin of, 83; use of, 83.
Inlaid tiles, 679-682.
Intermittent kilns with up draught, described 354, 356, *illustrated* 354, 355; with down draught, 356-363; horizontal, with single furnace, described 363, *illustrated* 363, 364.
Iridium as a colouring material for pottery, 414.
Iron as a colouring material for pottery, 409-410.
— lustres, 438.
— ore in natural clays, 57.
— oxides in natural clays, 54-55; proportion of oxide of iron in plastic bodies, 101.
— stone, use of the term, 7.

Italian faience works, 22-24: use of plumbiferous glaze, 22; introduction of stanniferous opaque enamels, 22-23; invention of majolica, 23; importance and principal seats of industry, 23-24; leading artists, 23-24; examples of, 23-24; Deck on majolica, 24; growth and decline of, 24.

J.

Jaeger type of vertical mill, described 126, *illustrated* 127; particulars of different models, 126.
Jannot type of vertical mill, described and *illustrated*, 125-126; pulveriser, described 164, *illustrated* 166.
Jigger, *illustrated*, 215; making of batts on the, explained 216-218, *illustrated* 217.
Johnson and Blake on the causes of plasticity of clay, 46.
Jolleys, described, 213-214; jolley heads, *illustrated*, 213, 214; upright jolley, use of 215, *illustrated* 216. *And see under* Moulding.
Jsoni, Style of Chinese porcelain of the time of the Dynasty of, 34.

K.

Kaolin, Discovery of use of, for porcelain manufacture, 35-36; beds discovered in Cornwall and at Alençon, 37; derivation of the word, 51*n*; pure, 59; alkaline, 59; silicious, 59; alkaline silicious, 59-60; ferruginous, 60; chief beds of, 60; examples of analyses of different, 65.
— earth as a raw material of glazes, 279; influence of firing on volume and density of, bodies, 306-307.
— pottery, 11.
Kerl, Bruno, System of classification of, 11-12; "Ceramic Industries" by, 11; examples of analyses of clays by, 66; analyses of halloysite and lenzenite by, 68.
Kilns, Reverberating, 117; sliding, 117. *See under* Firing.
Klaproth, Analysis of cymolithe by, 69.
Knaffl, Examples of analyses of clays by, 65, 66.
Knapp, System of classification of, 10.
Kolbe, System of classification of, 10-11.
Kouen-ou, first Chinese potter, 16.
Kung-Long, Present standard of Chinese porcelain dating from Dynasty of, 34; its characteristics, 34.

L.

Lacroix and invention of vitrifiable crayons, 441.
"La France," by Deck, quoted, 626-627.
Lambeth, Dutch factory at, 31; Messrs. Doulton's factory at, 34.
Latarche's actinometric pyrometer, 399.
Lathes for turning, described, 193-194; *illustrated*, 194.
Lead, Oxide of, in glazes, 275; oxides and salts of, as raw materials of glazes, 283-285; red and white, ditto, 284-285; ore, ditto, 285.
— lustres, 438.
Lecaze disaggregating stove, *illustrated*, 114-115.
Le Chatelier and the true formula for pure clay, 46; method of distinguishing hydrosilicates of alumina in natural clays, 53; on materials analogous to clay, 68; on composition of collyrite and allophane, 68-69; on composition of marls, 79; and dehydration of hydrosilicates of alumina, 88; his thermo-electric pyrometer, 399-400; and optical pyrometer, described 400-401, *illustrated* 401.
Leclaire filter press, described, 177-178; *illustrated*, 177.
Le Croisic, Italian factories at, 25.
Leeds factories, popularity and fame of their productions, 31.
Lenzenite, Use of, 68; where found, 68; analyses of, by Brongniart and Bruno Kerl, 68.
Lever press for moulding by compression, described, 226-227; *illustrated*, 225.
Levigating mills, described, 169; *illustrated*, 170.
Levigation, Use of, for determining texture of clays, 92-93; tests showing results obtained by, 94-95; use of, for testing silicious substances, 98; of sands, objects of, 146; methods of, 146-147.
Light bricks. *See under* Bricks.
Lignites as fuel, 327.
Lime, Use of, as a flux, 79; method of determining proportion of, in clay, 91-92; proportion of, in plastic bodies, 101; in glazes, 275; as a raw material of glazes, 282; carbonate and sulphate of, ditto, 282; phosphate of, ditto, 287; influence of, on fusibility of bodies, 303-304; defects arising from, in bodies, 314-315; basic fireclay goods with, 595; with lime and magnesia, 594-595. *See under* Carbonate, Sulphate.
Limoges, First hard porcelain works at, 37.
Limousin, greatest centre of hard porcelain production in France, 42.
Linant Bey, Discoveries by, in Egypt, 15.
Litharge as a raw material of glazes, 283-284.
Liverpool, the cradle of English soft porcelain manufacture, 37.
Loizeau grinder, Weidknecht-Schoeller's, described, 121-122; different patterns of, 122.
Louis XV., founder of Sèvres factory of soft porcelain, 37.
Luke, Guild of Saint, founders of Delft ware, 30.
Lustres, Metallic, decoration with, 436-438: gold, 437-438; platinum, 438; silver, 438; cantharides, 438; various other, 438.
Lustre ware, 552-554.

## M.

Macheleidt, chemist, porcelain works founded by, 36.
Maercker, Examples of analyses of clays by, 65.
Magnesia, Proportion of, in plastic bodies, 101; in glazes, 275; as a raw material of glazes, 283; influence of, on fusibility of bodies, 303-304; defects arising from, in bodies, 314-315; basic fireclay goods with, 593-594; with magnesia and lime, 594-595. *See under* Carbonate.
Magnesic fluxes, 82.
Magnesite, where found and used, 69; analysis of, 69.
Majolica, derivation of word, 23; origin of ware, 23; importance of manufacture in Italy, 23-24; Deck on, 24; growth and decline of, 24.
Majorca, the seat of manufacture of Hispano-Moresque faience, 21.
Malaguti and mistaken formula for pure clay, 45.
Manganese as a colouring material for pottery, 412.
Marbled effects, how obtained, 427.
Marco Polo and discovery of place of origin of Chinese porcelain, 35.
Maret, Examples of analyses of clays by, 66.
Mariette Bey on ceramics in Egypt, 15.
Marls, Use of, in place of clay, 69-70; use of, as fluxes, 79; Le Chatelier and Vogt and the composition of, 79.
Mechanical purposes, Porcelain for, 726-727.
Meissen, Discovery of kaolin by Böttcher at, 35-36; first hard porcelain works established at, 36.
— gilding, 437.
Memphite period, Discoveries relating to the, 15.
Meslans apparatus for analysis of gases, 393.
Mesuré and Nouel's pyrometric telescope, described and *illustrated*, 400.
Metals, Colouring, for pottery, 409-414; decoration with, 435-436.
Metallic lustres, Decoration with, 436-438; sulphides in natural clays, 55.
Mexico a birthplace of ceramics, 16.
Mica in natural clays, 53-54, 56.
Michaelis, Examples of analyses of clays by, 67.
Microscope, Use of, for determining texture of clays, 92.
Ming Dynasty, High degree of perfection attained in porcelain manufacture under the, 35.
Mingling as an operation in the manufacture of glazes, 289.
Mixing as an operation in the manufacture of glazes, 287-289, 292-295.
Möller, Examples of analyses of clays by, 65.
Molybdena in natural clays, 56.
Monumental earthenware, Persian, unequalled, 19-20.
Moors, Introduction of art of faience into Europe by the, 21.
Morel mill, The, 123.
Mortar, Fireclay. *See under* Fireclay goods.
Moss, Decorative effect known as, 441.
Moulding, 206-232:
By hand, 206-212: with wooden moulds, described 206-207, *illustrated* 206; with plaster moulds, described 207-212, *illustrated* 210, 212.
On the jolley, 212-220: machines for, described 212-216, *illustrated* 213, 214, 215, 216; processes of, explained 216-220, *illustrated* 217, 218, 219.
By compression, 220-231: moulds, described 220-225, *illustrated* 221, 222, 223; presses, described and *illustrated*, 225-231.
By slip casting, 231-232.
Moulding, Defects in bodies arising after firing from, 312; decorative, of body, 421-423; of plain ordinary bricks by hand, 450-452; by machine, 452-453; of ordinary tiles, 510-512; of paving tiles, 534; of argillaceous fireclay goods, 579-583; of feldspathic faiences, 641-647; of hard porcelain, 709-714.
Moulds for hand moulding, Wooden, described 206-207, *illustrated* 206; plaster, 207-209; for moulding on the jolley, 214-215; for moulding by compression, 220-225: squeezing moulds, described 220-223, *illustrated* 221, 222; compressing moulds, described 223-225, *illustrated* 223.
Mountain tiles, 509; manufacture of, 515.
Moustiers, New decorative art of, 27; history of the school, 28; Garnier on, 28; its wide influence, 28; at end of 18th century, 28.
Muffle kilns, described, 376-378; *illustrated*, 376, 377.
Muscovite. *See* Mica.

## N.

Nanking pottery, Origin of, 34.
Nantes, Italian factories at, 25.
Nature of the body, Influence of, on drying, 241-243.
Needham, Solution by, of the difficulty of stiffening bodies by artificial means, 174.
Netherlands. *See* Dutch faience.
Neutral atmosphere of kiln, 388 *et seq.*
Nevers faience, 26-27; Garnier on, 27; at close of 18th century, 28-29.
Newcastle-on-Tyne, Dry pulverisation of silex at, 73.
New Sèvres porcelain, 733-734.
Nickel as a colouring material for pottery, 412.
Nineveh, Discoveries in the ruins of, 15.
Non-plastic materials for ceramic bodies, 71-76: use and nomenclature, 71; silicious materials, 71-73; sands, 73-74; calcareous materials, 74-75; carbonaceous materials, 75; pulverised fired bodies, 75-76. *See* Grog, Sands, Silica.

Non-plumbiferous varnished faiences, Common, 605-606.
Nouel. *See* Mesuré.
Nuremberg faience, Characteristics of, 29-30.

O.

Oiron faience, 25; characteristics of, 25; classification and manufacture of, 601-602.
Opaque enamels, Definition of, 277; porcelain, use of the term, 7.
Opening materials for ceramic bodies. *See under* Non-plastic.
Optical pyrometer, Le Chatelier's, described, 400-401; *illustrated*, 401.
Order of Jerusalem, Persian art at Rhodes under, 22.
Ordinary bricks, Plain. *See under* Bricks.
— tiles. *See under* Tiles.
Organic materials in natural clays, 55.
Oriental porcelain, Chinese origin of, 34; characteristics of earliest productions, 34; progress in manufacture, 34; Nanking pottery, 34; perfection attained under Ming Dynasty, 34; further modifications, 34; present standard attained under Kung-Long Dynasty, 34; characteristics of Chinese porcelain, 34; erroneous classification of same, 34-35; localities of manufacture, 35; introduction into Europe, 35; Japanese porcelain, history and characteristics of, 35.
Ornamental bricks. *See under* Bricks.
Over glaze colouring, 431-435.
Oxide of iron, Method of determining proportion of, in clay, 91.
Oxidising atmosphere of kiln, 388 *et seq.*

P.

Padua majolica, 24,
Palissy, Bernard, biographical notes, 25-26; discovers secret of white enamel, 25; original faience by, 25-26; stove tiles and rustic "figulines" by, 26; estimate of, by Brongniart, 26; his secret dies with him, 26.
Panels in enamelled faience, 619-624.
Parian porcelain, 42, 736-737.
Paris, Early glazed vase industry at, 25.
Pastillage, 427.
Patanozzi, Antonio, and Urbino majolica, 23.
Paving tiles, Mechanical causes of disaggregation of, 557. *And see under* Stoneware.
Pebble work, 601, 635.
Pegmatite as a raw material of glazes, 279.
Percy, Examples of analyses of clays by, 66.
Perforating, 233.
Permeable pottery, 12-13: secondary characteristics of, 12-13; classes divided into, 13. *See* Porous pottery.
Perrot trial kiln, described, 321-322; *illustrated*, 320.
Persia, Monumental earthenware from, 20.
Persians, The ancient, as manufacturers of earthenware, 16.
Pesaro, Early use of plumbiferous glaze at, 22; majolica manufactures of 24; their leading artist, 24.
Philadelphia clay, Gold in, 56.
Phœnicians, Influence of the, on ceramics, 16.
Phosphate of lime, Use of, as a flux, 82.
Phosphated porcelain, Soft, 728-730.
Phospho-calcareous fluxes, 82.
Phosphoric acid in natural clays, 55; proportion of, in plastic bodies, 101; in glazes, 274.
Phosphorite, Use of, as a flux, 82; where found, 82.
Photography as a means of decorating pottery, 441.
Pietersz, Herman, Adrian and Gerrit, and Delft, 30.
Pipe machine, Combined pug. *See* Blade propellers.
— — Spiral. *See* Screw propellers.
Pipes, 537-541: for gas channels, 537-541; for water courses, 541; mechanical causes of disaggregation of, 557. *See under* Stoneware.
— Tobacco, Manufacture of, 550-552; centres of manufacture of, 552.
Pipeclay faiences, 601, 631-635.
Piston propellers. *See under* Propellers.
Plain ordinary bricks. *See under* Bricks.
Plaques, Clay, ancient chronicles on, 15.
Plaster moulds, 207-209; moulding with, described 209-212, *illustrated* 210, 212.
Plastic bodies, Definition of, 1.
Properties and composition of, 100-111: chemical composition of, 100-103; forms and proportions of water in, 103-104; texture of, 104-107; consistency of, 107-108; plasticity of, 108-111.
Preparation of raw materials, 111-149. *See under* Raw materials.
Preparation of bodies, 150-181. *See under* Bodies.
*See also under* Consistency, Plasticity, Texture.
Plasticity, Variation of, in proportion to consistency and pressure, 108-111; influence of water in formation by hand, 108-109; and by means of machinery, 109-110; summary of relations between plasticity and consistency and pressure corresponding to mode of formation, 110.
— of clays, 95-97: basis of, 95; estimation of, by touch, 95; Bischof's comparative process, 95-96; results of tests on French clays with Fontainebleau sand, 96; results obtained with quartzy sand, 96-97; use of briquettes to determine, 97.
Platinum as a colouring material for pottery, 413; use of, in metallic state for decorating pottery, 435, 436; lustre, 438.
Plumbiferous glaze, 22; varnished faience, common 602-605, common non- 605-606.

Plungers. *See* Piston propellers.
Pontaillier, Early glazed vase industry at, 25.
Porcelain, misuse of the term, 7; clay pottery, 11; influence of, on stanniferous enamelled faience in France, 29. *See* Chinese porcelain, Opaque porcelain.
Porcelain, 700-738:
Classification, 700-701.
Hard porcelain, 702-728: Porcelain for table ware and for decoration, 702-724: composition of the body, 702-707; composition of the glaze, 707-708; preparation of the body, 708-709; moulding, 709-714; drying, warming and application of the glaze, 714-715; burning, 715-718; saggering, 718-719; decoration, 720-723; general arrangements of works, 723-724.—Porcelain for the fire, 724-725.—Porcelain for electrical conduits, 725.—Porcelain for mechanical purposes, 726-727.—Architectural porcelain, 727.—Dull or biscuit porcelain, 727-728.
Soft phosphated or English porcelain, 728-730.
Soft vitreous or French porcelain, 731-732.
Soft vitreous or New Sèvres porcelain, 733-734.
Argillaceous soft or Seger's porcelain, 735-736.
Dull soft or Parian porcelain, 736-737.
Dull Feldspathic soft porcelain, 737-738.
*Illustrations*: Mechanical making of plates, 712; wheel for forming oval pieces with a templet, 713; methods of saggering, 719; muffle kiln, 723; porcelain objects for electrical channels, 726.
Porcelain clay pottery, 11.
— works, General arrangements of, 723-4.
Porosity, Importance of, as a characteristic of ceramic ware, 12.
Porous pottery, 10, 11. *See* Permeable pottery.
Potash, Influence of, on fusibility of bodies, 303-304; carbonate of, as a raw material of glazes, 281; and nitrate of, 281-282.
Poterat, Louis, creator of the Rouen style, 27; and the discovery of soft porcelain, 37.
Potter's cog wheel, described 185-186, *illustrated* 185; cone drum wheel, described 188-189, *illustrated* 188; machine wheels, described 186-189, *illustrated* 186, 187, 188; string wheel, described 185-186, *illustrated* 185; wheel, described 184-185, *illustrated* 184.
Pottery, Derivation of the word, 2*n*; common, 547-549; for water, 549-550. *See* Ceramic ware, Clayey pottery, Dense pottery, Impermeable pottery, Kaolin pottery, Permeable pottery, Porcelain clay pottery, Porous pottery, Solid pottery.
Pouillet, Results obtained by, in measuring temperature by eye according to colour of ware or of walls of kiln, 395.
Pouring, Application of glazes by, 297.
Pourtalès, Comte de, Examples of Palissy's art in collection of, 26.
Presses for moulding by compression, described and *illustrated*, 225-231; by shock, 225-228; by pressure, 229-231; for manufacture of plain ordinary bricks, 462-468; of ordinary tiles, 516-524; of paving tiles, 535-536.
Pressing, Defects in bodies arising after firing from, 312.
Pressure, Presses acting by, described, 229-231; *illustrated*, 228, 229, 230.
Profiles for moulding on the jolley, 215-216; profile tool, *illustrated*, 215.
Propellers, Piston, described 198-199, *illustrated* 198, 199, 200; blade, described 199, *illustrated* 201; single screw, described 199-203, *illustrated* 201, 202; twin screw, described 203, *illustrated* 204; cylindrical, 204; for manufacture of plain ordinary bricks with pistons, 455; with blades, 455; with single screw, 455 *et seq.*; with two screws, 462; with cylinders, 462.
Prössel, Composition of glazes for pipeclay faiences by, 633-634; for feldspathic faiences, 638.
Prosser, the inventor of dull feldspathic soft porcelain, 737.
Pug. *See under* Fireclay goods.
Pugging, Primitive methods of, 154; vertical pug mills, described 154-156, *illustrated* 156; table of conditions of working of vertical pug mills with mechanical motive power, 156; horizontal pug mills, described 157-160, *illustrated* 157, 158, 159; table of conditions of working of horizontal pug mills with mechanical motive power, 158; rolling mills and pug mills combined, described 160, *illustrated* 157, 161, 162; object of, 181.
Pulverisation as an operation in the manufacture of glazes, 288-289.
Pulverisers, Use of, 163-164; Jannot's, described 164, *illustrated* 166.
Purification. *See under* Raw materials.
Purifier, Electrical, for the manufacture of glazes, described, 294-295; *illustrated*, 296.
Pyrometers, 398-401: Wedgwood's, based on expansion of bodies, 399; Saintignon's, by circulation of water, 399; Latarche's actinometric, 399; Siemens' electric, 399; Le Chatelier's thermoelectric, 399-400; Mesuré and Nouel's pyrometric telescope, described and *illustrated*, 400; Le Chatelier's optical, described 400-401, *illustrated* 401.
Pyrometric telescope, Mesuré and Nouel's, described and *illustrated*, 400.
— tests, 395-401: specimens of the body, 396; metals, 396; Seger's, 396-398; in use, 398; illustration of and explanation, 398. *See also* Pyrometers.

## Q.

Quarries, Charging with, described and *illustrated*, 384.
Quartz in natural clays, 56, 57; how and where found, 72; pulverisation of, 72-73; as a refractory material, 83; method of disaggregation in use for, 116-117.
Queen's ware, origin of the term, 31.

## R.

Raeren, Stoneware first manufactured at, 32; its characteristics, 32-33.
Raphael, Works of, reproduced in majolica, 23-24.
Rapidity of drying, Influence of, 247-248.
Raw materials (other than clays) of ceramic bodies, 67-85:
Classification of, 67: analogous to clay, 68-70; agglomerative and agglutinative, 70-71; opening or non-plastic, 71-76; fusible, 77-82; refractory, 83-85.
Trials of, 98-99: silicious substances, 98; alkaline fluxes, 98-99; sulphate of lime, 99.
*See also* Clays, trials of.
Raw materials, Bourgerel's graphic method of determining proportion of, for a given plastic composition (*illustrated*), 102-103.
— — Preparation of, 111-149:
Disaggregation, 111-130: processes of, 111; natural, 111-113; by heat, 113-118; mechanical, 118-130. *See under* Disaggregation.
Purification, 130-149: processes of purifying, 130-132. *See* Chemical purifying, Electric purifying, Sifting, Sorting, Ventilation, Washing of clays.
— — of glazes, 278-287; preparation and mixing of, 287-289.
Rectangular kiln with down draught, described 357-358, *illustrated* 357; with upper dome, 358-361; with lower dome, 361.
Reds, Preparation of, for pottery, 416-417; how obtained, 425.
Red hematite in natural clays, 57.
— lead as a raw material of glazes, 284.
Reducing atmosphere of kiln, 388 *et seq.*
Refractory clays, 60-62: pure, 60-61; plastic, 61; silicious, 61; chief beds of, 61-62; examples of analyses of different, 65-66.
— fired bodies, Definitions of, 13.
— materials for ceramic bodies, 83-85.
Regenerators, 378-380: a misnomer, 378*n*; intermittent, 379; continuous, described 379-380, *illustrated* 380; brick for same, *illustrated*, 379.
Repairing, 233.
Repressing of plain ordinary bricks, 468-475.
Reverberating kilns, Use of, for disaggregation, 117.
Revolving dryer, *illustrated*, 262.
Reygens, Augustijn, and Delft, 30.
Richter, Examples of analyses of clays by, 66.
Ridge tiles, 510.
Ringler and the sale of secret of porcelain manufacture, 36; with Hannong founds factories, 36; robbed of his secret, 36.
Robbia family, Influence of, on ceramic art of Italy, 22-23; Andrea della, 23; Girolomo della, 25; Luca della, creator of new kind of faience in Italy, 22-23.
Roller dies, *illustrated*, 204.
Rolling grinders for mechanical disaggregation, 127-129: use of requirements of, 127-128; Boulet grinder with plain rollers, *illustrated*, 128; Schlickeysen toothed roller machine, 128; treatment of clays with, 128-129; specifications, 129.
— mills, described, 153; method of estimating production and motive force of, 153; pugging with, 153-154; with circular fluting and of conic form, described 153-154, *illustrated* 154, 155; and pug mills combined 160, *illustrated* 157, 161, 162.
Romans, creators of fired wares for building, 18; their art compared with Greek art, 19; its decline, 19; revived by Renaissance, 19.
Rörstrand crockery ware, 31.
Rouen faience, 27; importance of its style, 27; at end of 18th century, 28.
Rough stuff. *See* Grog.
Round kiln with up draught, described 356, *illustrated* 355; with down draught, described 358, *illustrated* 359; with upper dome, described 358, 361, *illustrated* 360; with lower dome, described 361, *illustrated* 362.
Rovigo, Francesco da, and Urbino majolica, 23.
Runcorn, Dry pulverisation of silex at, 73.

## S.

Saggarah, Pyramid of, discoveries in, 15.
Saggers, *illustrated*, 385; charging in, 384-386; manufacture of, 581-582; moulding machine for, described 582-583, *illustrated* 582; setting and placing of feldspathic faience in, 652-655; saggering of hard porcelain for table ware and decoration, 718-719.
Saint-Amand factories of soft porcelain, 37.
Saint-Antoine, Pure allophane found at, 69.
Saint-Cloud, Discovery of soft porcelain at, 37.
St. Petersburg porcelain works, 36.
Saint-Porchaire, seat of manufacture of "Henri Deux" faience, 25.
Saint-Sever, Collyrite extracted at, 69.
Saint-Valéry-sur-Somme, Dry pulverisation of silex at, 73.
Saint-Yrieix beds of kaolin, Discovery of, 37.
Saintes, Early glazed vase industry at, 25.

Salts, Use of, as fluxes, 77-78.
Salting of stoneware pipes, 687-690.
Salvetat, System of classification of, 9-10; and mistaken formula for pure clay, 45; examples of analyses of clays by, 65, 66, 67; on the chemical purifying of raw materials, 148; on the composition of black lustre, 554; on the composition of Oiron faience body, 601.
Sands, Composition of, 73; quartzy, 73-74; feldspathic, 74; micaceous, 74; ferruginous, 74; calcareous, 74; clayey, 74; composite varieties of, 74; saline, 74.
Sanitary stoneware, 691-692.
Savignies, Early glazed vase industry at, 25; stoneware, 33.
Savona majolica, 24.
Saxony porcelain ware, 31.
Scaling, Cause of, 317; remedy for, 318; action of silica in respect of, 318-319; action of fluxes in respect of, 319.
Schlickeysen toothed-roller grinder, 128.
Schloesing and the true formula for pure clay, 46.
Schmelzer blunger, Method adopted in, 143.
Schmidt disaggregating stove, *illustrated*, 115-116; use of rolling machine as propeller in purifier by, 138.
Schoeller. *See* Weidknecht-Schoeller.
Schone, Apparatus proposed by, for separation of grains in clays, *illustrated*, 93-94.
School of Mines, Paris, Examples of analyses of clays by, 65.
Schulz, Apparatus proposed by, for separation of grains in clays, *illustrated*, 93.
Schwarz, Examples of analyses of clays by, 66.
Scraping, 233.
Screw press for moulding by compression, described, 227-228; *illustrated*, 226, 227.
Screw propellers. *See under* Propellers.
Seger and the true formula for pure clay, 46; on yellow and green settlings on terra cotta of clay from north of Germany, 56; examples of analyses of clays by, 65, 66, 67; on transformation of crystalline into amorphous silica, 72; system of classification of sizes of grains in clays by, 94; tests on texture of clays showing results obtained by levigation by, 94-95; pyrometric tests by, 396-398; composition of bodies for feldspathic faiences by, 637; analyses of unburnt porcelain bodies by, 704; Seger's porcelain, 735-736; "Seger's Gesammelte Schriften," quoted, 735.
Semi-continuous kiln, *illustrated*, 375.
Separators, described, 144; *illustrated*, 144, 145.
Settling tanks, Use of, explained, 144-146; *illustrated*, 145.
Sèvres, Establishment of soft porcelain factory by Louis XV. at, 37; secret of hard porcelain acquired, 37.
Shape, Influence of, on drying of bodies, 246-247.
Shells in natural clays, 57.
Shock, Presses acting by, 225-228.
Shrinkage as a basis for measuring temperature of kiln, 395.
Sicily, Arabian faience ware in, 22.
Siculi-Arabian faience ware, 22.
Siegburg stoneware, 33.
Siemens' electric pyrometer, 399.
Sieve, Use of, for determining texture of clays, 92.
Sifting as a process of purifying raw materials, 130, 133-138; of dry pulverulent materials, 133; of liquid materials, 134; of pasty materials, 133; Chambrette purifier, described 134-135, *illustrated* 134; Groke purifier, described and *illustrated*, 135; Chambrette hydraulic purifier, described 135, *illustrated* 136; Brethon (Delahaye) hydraulic purifier with screw propeller, described 136-137, *illustrated* 137; use of rolling machines as propellers, 137-138; methods of, 173-174; apparatus for, described 173-174, *illustrated* 173; application of glazes by, 297-298.
Silex in natural clays, 57; how and where found, 73; pulverisation of, 73; where industry carried on, 73; as a refractory material, 83; method of disaggregation in use for, 116-117.
Silica in natural clays, 54; importance of, in ceramics, 71; forms of, 71; transformation of crystalline into amorphous, 72; as a refractory element for clays, 83; different forms of, 83-84; proportion of, in plastic bodies, 100; in glazes, 274; as a raw material of glazes, 278; influence of, on fusibility of bodies, 304-305; action of, in respect of scaling and crazing, 318-319; influence of, on pure clay as affecting its fusibility, 574-575; mixtures of, and alumina, scale of fusing temperatures of, 575. *See* Amorphous silica, Crystalline silica.
Silicates as raw materials of glazes, 278-279.
Silicate of lime. *See* Marls.
Silicious faiences, 601, 624-631; fireclay goods—*see under* Fireclay goods; substances, levigation as a test for, 98; chemical analysis of, 98.
Silver as a colouring material for pottery, 413; use of, in metallic state for decorating pottery, 435, 436; lustre, 438.
Slabs, Charging with, described and *illustrated*, 384.
Slapping. *See* Wedging.
Sliding kilns, Use of, for disaggregation, 117.
Slips, Coloured, 426-427.
Slipping, 234, 235-237; the process explained, 18-19.
Slow firing, 387.
Smoking, 386-387.
Soda, Influence of, on fusibility of bodies, 303-304; carbonate of, as a raw material of glazes, 280-281; sulphate of, as a raw material of glazes, 281.
Sodium chloride as a raw material of glazes, 281.

Soft body, Plastic method of preparation of, 151-160.
— bodies, Brongniart's use of the term, 8, 9.
— glazes, Definition of, 277.
— porcelain, Discovery of, 37.
— porcelains, 728-738: phosphated or English, 728-730; vitreous or French, 731-732; vitreous or New Sèvres, 733-734; argillaceous or Seger's, 735-736; dull or Parian, 736-737; dull feldspathic, 737-738.
Solid pottery, 10.
Soliman II., Brilliant period of Persian art at time of, 22.
Soluble salts in bodies, Defects arising from, 313-314; in clay, method of determining proportion of, 92.
Sorting as a process of purifying raw materials, 130, 132-133; manual, 132; mechanical, 132; Brewer purifying machine, described and *illustrated*, 132-133.
Spraying, Application of glazes by, 298.
Sprigging, 235.
Sprinkling, Application of glazes by, 297-298.
Square kiln with up draught, described, 354, 356; *illustrated*, 354.
Squeezing moulds. *See under* Moulds.
Staffordshire, Manufacture of porcelain with kaolin introduced into, 37-38; combined factories of faience and stoneware in, 34.
Stampers for mechanical disaggregation, 118-120; disadvantages of, 119; described, 119-120; *illustrated*, 119.
Stamping, 422-423.
Stanniferous opaque enamels, Introduction of, in Italy, 22.
Statues, 545-547; stoneware, 697-698.
Steatite. *See* Talc.
Steinbrecht, Examples of analyses of clays by, 65.
Sticking, explained, 233-234, 235; *illustrated*, 234.
Stiff body, Plastic method of preparation of, 160-163; machinery for, described 161-163, *illustrated* 163, 164, 165.
Stiffening, 174-181; the operation explained, 174; by artificial means, 174-175; the difficulty overcome by Needham, 174; Talabot's filter, 175. *And see* Filter presses.
Stoneware, Definition of, 14; history of, among the Ancients, 32; in the Middle Ages, 32; establishment of the manufacture in the 15th century, 32; earliest factories, 32-33; history of, in France, 33; in England, 33-34.
Stoneware, 660-699:
Classification, 660-663.
Stoneware properly so called, 664-698:
Paving tiles, 664-682: forms and dimensions, 664-665; composition, 665-668; colouring, 668-669; methods of manufacture, 669-670; manufacture in plastic body, 670-675; manufacture in dry body, 675-679; inlaid tiles, 679-682; tests, 682.
Stoneware (*continued*)—
Stoneware properly so called (*contind.*)—
Pipes, 682-691: forms and dimensions, 682; composition, 682-683; moulding, 683-687; burning and salting, 687-690; tests, 690-691.
Sanitary ware, 691-692.
Stoneware for food purposes and chemical productions, 692-695.
Architectural stoneware, 695-697.
Vases, statues, and other decorative objects, 697-698.
Fine stoneware, 698-699.
*Illustrations:* Paving tiles, 664; machines for expressing tiles, 670, 671; cutting apparatus for tiles, 672; machine for polishing tiles, 673; machine for trimming tiles, 674; hydraulic press for moulding tiles, 676; kiln with continuous firing, with several chambers, heated by gas, 678; templet for inlaid tiles, 679; moulding of inlaid tiles, 680, 681; pipes, 683; machines for expressing pipes, 685, 686; machine for finishing pipes, 687; semi-continuous kiln for burning pipes, 689; sanitary pottery, 692; stoneware for preparing food and chemicals, 693; kiln for stoneware, 694.
Stöpzel, founder of Vienna porcelain works, 36.
Stoves, Varnished faience, 613.
Stove tiles in enamelled faience, 619-624.
Strassburg faience, Characteristics of, 28; Garnier on, 28; Hannong family the founders of, 28; factories of soft porcelain, 37.
Straw as a fuel, 327.
Streaks as a means of decoration, 439.
Strontia in glazes, 275; as a raw material of glazes, 283.
Sulphate of lime in natural clays, 55; use of, as a flux, 79-80; testing of, by chemical analysis, 99.
Sulphide of iron in natural clays, 55, 57.
Sulphuric acid, Use of, to ascertain constitution of clay, 86-87; proportion of, in plastic bodies, 101.
Sulphurous fumes in atmosphere of kilns, Defects in bodies due to, 313.
Susa, Monumental earthenware from, 20.
Sweden, Stanniferous ware factories of, 31.
Switzerland, Stanniferous ware factories of, 31.

## T.

Tables—
Brongniart's, of the classification of pottery ware, 8.
Author's, of the classification of pottery ware, 14.
Examples of analyses of clays, 65-67.
Chemical composition of feldspars and feldspathic rocks, 80-81.
Examples of analyses of infusorial earths, 83.
Examples of analyses of samples of gannister of different origin, 84.

Tables (*continued*)—
Examples of analyses of bauxites, 85.
Tests on texture of clays by Seger, showing results obtained by levigation, 95.
Results of tests on French clays with Fontainebleau sand by M. Bischof to determine plasticity, 96.
Results of tests on clays with quartzy sand by M. Bischof to determine plasticity, 97.
Quantity of water bodies of different texture should contain for the different degrees of consistency, 108.
Classification of machines according to their mode of action in mechanical disaggregation, 111.
Results obtained with different models of the Carr disintegrator, 121.
Details of construction of the four standard types of the Loizeau grinder, 122.
Results obtained with different current models of chopping grinders, 125.
Ditto of vertical roller mills, 126.
Ditto of roller grinders, 129.
For estimating production and motive force of rolling mills according to the quality of the body, 153.
Of conditions of working of vertical pug mills with mechanical motive power, 156.
Of conditions of working of horizontal pug mills with mechanical motive power, 158.
Volume of body stiffened by different sizes of filter press, 179.
Weight and volume of a plastic clay made by hand in the form of cylinders during whole time of drying, 239-241; graphic representation of same, 241.
Results of trials with a variety of clays by measuring duration of drying and shrinkage of spaces, 241-242; graphic representation of same, 242.
Effects of modification of consistency of a body on duration of drying, shrinkage and proportion of spaces, 243-244; graphic representations of same, 244, 245.
Results obtained with three trial spheres of different diameters to illustrate influence of the shape of the objects on drying of bodies, 246.
Amount of heat absorbed and water evaporated by 1 $m^3$ of dry air at every 5° of temperature, 250.
Amount of heat expended to evaporate 1 kg. of water at different temperatures, 256.
Number of revolutions and motor force employed by ventilating fans of different diameters to produce a given volume of air per minute, 258.
Proportion of four alkaline earthy bases of glaze, 275.
Limits of variation in composition of glasses, 279.

Tables (*continued*)—
Depression, volume and weight of air delivered per second by a chimney 1 metre high and 1 square metre in section for increasing temperature *t*, 348.
By Pouillet showing results of measuring the temperature by eye according to colours of ware or of walls of kiln, 395.
Of metals for measuring the temperature by melting and volatilising in the kiln, with the temperature corresponding with their change of state, 396.
Composition and order number of Seger's series of pyrometric tests, 396-397.
Order number of tests in use in various potteries, 398.
Corresponding variations of colour and temperature in tests for gold, 442.
Dimensions and volume of best known types of ancient and modern bricks, 449.
Production in twenty-four hours of continuous kilns of various dimensions and varying volume of compartment, 488.
Composition of black lustre according to Salvetat, 554.
Composition of the seven typical clays of M. Bischof, 577.
Composition of the body of a number of enamelled faiences by Brongniart, 616.
Composition for enamel of faience by Brongniart and Bastenaire-Daudenart, 617.
Results of analyses of different bodies of burnt porcelains, 703.
Results of analyses by Seger of different unburnt porcelain bodies, 704.
Composition of the four types of hard porcelain, 704, 706.
Chemical composition of some glazes for hard porcelain, 707.
Table ware, Porcelain for. *See under* Porcelain.
Talabot's stiffening filter, 175.
Talavera faience, 31.
Talc, Composition and analysis of, 69; where used, 69.
Tarring of black tiles, 531-532.
Telescope, Mesuré and Nouel's pyrometric, described and *illustrated*, 400.
Tell-el-Yadouai, Discoveries in the temple of, 15.
Temperature, Defects in bodies due to wrong, in firing, 312; defects in glaze due to wrong, 316; agreement of bodies and glazes in respect of, 316-317; measuring the, 394-401: by eye, 394-395; by colour of ware or of walls of kiln, 395; by shrinkage, 395; by pyrometric tests, 395-401. *See also under* Pyrometric.
Terra cotta, Definition of, 13; invention of manufacture of, 14-16; use of, by Romans, 38.

Terra cotta lumber, 501*n*.
Terra cottas, 446-567:
Classification of, 447-448.
Bricks, 447-503: plain ordinary, 448-492; hollow, 492-494; ornamental, 494-499; vitrified, 499-501; light, 501-503.
Tiles, 503-533: ordinary, 503-531; black, 531-533.
Paving tiles, 533-537.
Pipes, 537-541.
Architectural terra cottas, 542-545.
Vases, statues and decorative objects, 545-547.
Common pottery, 547-549.
Pottery for water and filters, 549-550.
Tobacco pipes, 550-552.
Lustre ware, 552-554.
Properties of terra cottas, 554-559: causes of disaggregation and the remedies, 554-559.
Tests for terra cottas, 559-567: samples, 559; general directions, 559-560.
Physical tests, 560-564: observation of the structure or homogeneousness, 560; specific weight, 560-561; apparent density, 561; absolute porosity, 561; relative porosity or the weight of water absorbed in a given time, 561-562; permeability, 562; tests for the resistance to frost, 563-564.
Mechanical tests, 564-566: resistance to being broken by crushing, 564; resistance to breaking by bending, 564-565; resistance to being worn by rubbing, 565; resistance to breaking by a blow, 566; resistance to breaking by internal pressure, 566.
Chemical tests, 566-567: testing for lime and magnesia, 566; determination of the soluble salts, 567.
*Illustrations:* Mill for mixing, 450; open mould, 452; die for plain bricks, 454; brick machines, 456, 457, 459, 463; cutting apparatus, 460, 461; brick presses, 464, 465, 467, 468, 469; brick moulds, 466; repressing machines, 470, 471, 472, 473, 474; drying bricks, 475, 476, 477; wheelbarrow, 477; little waggon, 478; elevator, 479; waggon for drying sheds, 481; drying sheds for bricks, 482, 483; burning in the open, 485; kiln with continuous firing, for solid fuel, 487; brick kiln, 489; temporary brick kiln, 490; hollow bricks, 493; flooring bricks, 494; repressed ornamental bricks, 495; ornamental bricks for mouldings, 496; die for bricks for mouldings, 496; hollow ornamental bricks, 497; dies for hollow bricks, 498, 499; kiln for paving bricks, 500; Roman tiles, 503; tiles of the Middle Ages, 504; round tiles, 505; rib tiles, 506; flat tiles, 506; scale tiles, 507; German flat tile, 507; lozenged tiles, 508; Marseillaise tile, 509; mountain tiles, 510; hollow tile, 511; apparatus for cutting flat tiles, 513, 514; manufacture of flat tiles, 514; method of making flat
Terra cottas (*continued*)—
*Illustrations* (*continued*)—
tiles in a packet, 515; manufacture of round tiles, 516; machine for the cakes of body, 517; patterns and moulds for tiles, 518; press for making plaster moulds, 518; presses for tiles, 518, 519, 522; machines for slabs (cakes of paste), 520, 521; framework for a tile, 524; wheelbarrow for tiles, 524; charging of tiles and bricks, 525; fixed firebrick furnaces, 527; continuous kiln for gas fuel, 529; continuous kiln with trenches, 530; kiln for blueing, 532; press for paving tiles, 536; types of pipes for conveying gas, 538; machines for pipes, 539, 540; draw plate for drainage pipes, 542; moulding of tobacco pipes, 550; burning of tobacco pipes, 551; apparatus for neutralising action of lime and magnesia, 558.
Terra cottas, French Government methods of testing, 559-567.
Terra cottas, Fireclay, chemical classification of, 569.
Texture of clays, 92; methods of testing the, 92-95; apparatus for determining the (*illustrated*), 93-94.
— of plastic bodies, 104-107: importance of determining proportion of foreign substances, 104-105; quantities of water required to be added to 100 parts of dry materials differently proportioned to obtain bodies of equal consistency, 105-106; effect of water on the density of plastic bodies, 106-107; effect of the electricity of air in plastic bodies, 107.
Thai-Yong-Youen, Important developments in manufacture of Chinese porcelain under the Dynasty of, 34.
Theban period, Discoveries relating to, 15.
Thermic yield of kilns, 402-403; causes of loss of heat, 404-406.
Thermo-electric pyrometer, Le Chatelier's, 399-400.
Throwing, 184-194: potter's wheels, described 184-186, *illustrated* 184, 185; mechanical wheels, described 186-189, *illustrated* 186, 187, 188; processes of throwing, described 189-193, *illustrated* 190, 191, 192; turning, explained, 193-194; turning lathe, *illustrated*, 194.
Thun factories and their peculiar style of decoration and glazing, 31.
Tile works, General arrangements of, 528-531.
Tiles, 503-533:
Ordinary, 503-531: forms and dimensions, 503-510; moulding of tiles, 510-512; manufacture by expression, 512-516; manufacture in a press with semi-soft or semi-stiff body, 516-520; manufacture in a press with stiff body, 520-523; drying, 524-525; burning, 525-528; general arrangements of tile works, 528-531.
Black, 531-533.
Tiles, Mechanical causes of disaggregation of, 557.

Tiles, Encaustic, 611-613.
— Encaustic dust, 679.
— Inlaid, 679-682.
— Paving, 533-537. *See under* Stoneware.
— Stove, in enamelled faience, 619-624.
Tin, Oxide of, in glazes, 276; as a raw material of glazes, 285-286.
Tin ash as a raw material of glazes, 286.
Tincal as a raw material of glazes, 280.
Ting, Improvements in Chinese pottery under the Dynasty of, 34.
Titanic acid in a natural clay discovered by Forbes, 56.
Titanium in natural clays, 56; as a colouring material for pottery, 413.
Tobacco pipes, 550-552.
Tralles, Bricks used in palace of Attalus at, 15.
Transparent glazes, Definition of, 277.
"Treatise on Ceramic Industries," division of the work, 3-4.
Trickling, Cause of, 316.
Truhod, Examples of analyses of clays by, 66.
Tunnel dryer, *illustrated*, 263.
Turgot, patron of Limoges hard porcelain works, 37.
Turning, 193-194; lathe, *illustrated*, 194.
Tuscany boracic acid as a raw material of glazes, 279-280.

## U.

Under glaze colouring, 427-430.
Undercutting, 233.
Uranium as a colouring material for pottery, 412-413.
Urbino, Majolica manufactures of, 23-24.
Utah, Pure allophane found in, 69.

## V.

Vallecas, Magnesite found at, 69.
Vallendar white clay, Peculiarity of, 55.
Vanadium in natural clays, 56.
Van Eenhoorn and Delft, 30.
Varnished faiences. *See under* Faiences.
— wares, French Board of Health method of testing harmlessness of, 604-605.
Vasaro, Gironimo. *See* Pesaro.
Vases, 545-547; varnished faience, 613-615; stoneware, 697-698.
Vedas of India, Mention of pottery in the, 15-16.
Velten clay, Use and composition of, 620-621.
Venice majolica, 24.
Ventilating fan for drying, *illus.*, 257.
Ventilation as a process of purifying raw materials, 147; drying by, 256-258.
Ventilators, Mechanical, use of, for drying, 257-258.
Verblender, 496-497.
Verona majolica, 24.
Vertical mills for mechanical disaggregation, 125-127: advantages of, 125; description of, 125; Jannot type, described and *illustrated*, 125-126; Jaeger type, described 126, *illustrated* 127; particulars of different models, 126; mills with movable slab, 126-127; the Chambers mill, described and *illustrated*, 126-127.
Vienna, Establishment of porcelain works at, 36.
Vilate, Lenzenite found at, 68.
Violets, Preparation of, for pottery, 417; how obtained, 426.
Vitreous porcelain, Soft, 731-732, 733-734.
Vitrifiable clays, 62-63: alkaline, 63; ferruginous, 63; best known beds of, 63; alkaline ferruginous, 66; examples of analyses of different, 66; use of, for paving tiles, 665.
— crayons, Use of, for decorating pottery, 441.
Vitrification as an operation in the manufacture of glazes, 289-292.
Vitrified bricks. *See under* Bricks.
— glazes for faiences, Analyses of, 623-624.
Vogt and the true formula for pure clay, 46; on the plasticity of clay, 47; method of proving presence of kaolinite in clay of, 53; on alkalies in natural clays, 53; on composition of allophane, 69; and of marls, 79.
Volatilisation, Application of glazes by, 298.
Volume, Influence of firing on, of bodies, 305-308; graphic representation of same, 307.
Von Gohren, Examples of analyses of clays by, 65.

## W.

Wan-Ti, Emperor, First mention of Chinese impermeable ware in the time of, 16.
Ware, derivation of the word, 2*n*. *See* Ceramic ware, China ware, Green ware.
— Lustre, 552-554.
Warming of hard porcelain, 714-715.
Washing, Use of, to ascertain constitution of clay, 87,
Washing of clays, Object of, 138; use of, restricted by cost, 138; processes of, 138; blunging of clay, 138-143; by hand, 139; hydraulic, 139; mechanical blungers, described and *illustrated*, 139-143; method adopted in Schmelzer's machine, 143; separation of grit and sand, 143-144; separators, described 144, and *illustrated* 144, 145; placing of clay in decanting tanks, 144-147; use of settling tanks, explained 144-146, *illustrated* 145; use of filter presses in connection with settling tanks, 146; levigation of sands, objects of, 146; methods of, 146-147.
Water, Proportion of, in combination in a plastic body, 103; proportion of hygrometric, in a plastic body, 104; of formation in a plastic body, 104; quantities of, required to be added to 100 parts of dry materials differently proportioned

to obtain bodies of equal consistency, 105-106; effect of, on the density of plastic bodies, 106-107; quantity of, required to obtain different degrees of consistency in plastic bodies, 108; influence of, in formation by hand, 108-109; and by means of machinery, 109-110; pottery for, 549-550.
Water courses, Pipes for, 541.
Water-lubricated die, described, 197-198; *illustrated*, 197.
Wedging, the operation explained, 181; machine described, 181.
Wedgwood, Josiah, Influence of, on progress of stoneware manufacture in England, 33-34; his pyrometer, 399.
Weidknecht - Schoeller's "Loizeau" grinder, 121-122; different patterns of, 122.
Wei-Tsin, Style of Chinese porcelain of the time of the Dynasty of, 34.
Whites, Preparation of, for pottery, 414; how obtained, 424.
White bottle glass as a raw material of glazes, 279; limits of variation in composition of, 279.
— lead as a raw material of glazes, 284-285.
Wiesnegg test kilns, described, 321-322; *illustrated*, 320, 321.
Wimmer, Examples of analyses of clays by, 67.
Window glass as a raw material of glazes, 279; limits of variation in composition of, 279.
Wood as a fuel, 325-326; heating by, 330-332.
Wooden moulds, described, 206-207; *illustrated*, 206.
Works quoted—
Appert and Henrivaux' "Glass and Glassworks," 272, 278.
Brongniart's "Treatise on the Ceramic Arts," 7, 18.
Bruno Kerl's "Ceramic Industries," 11.
Deck's "La France," 626-627.
"Seger's Gesammelte Schriften," 735.
Working of kilns. *See under* Firing,
Worm propeller. *See* Screw propellers.

## Y.

Yellows, Preparation of, for pottery, 416; how obtained, 425.
Yellow limonite in natural clays, 57.
Yield, Thermic, of kilns, 402-403; causes of loss of heat, 404-406.
Young-Thing, Characteristics of Chinese porcelain under, 34.

## Z.

Zinc, Oxide of, in glazes, 276; as a raw material of glazes, 287.
Zürich factories and their stoves, 31.

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**LUBRICATING OILS, FATS AND GREASES:** Their Origin, Preparation, Properties, Uses and Analyses. A Handbook for Oil Manufacturers, Refiners and Merchants, and the Oil and Fat Industry in General. By GEORGE H. HURST, F.C.S. Second Edition. Sixty-five Illustrations. 313 pp. Demy 8vo. 1901. Price 10s. 6d.; India and Colonies, 11s.; Other Countries, 12s.; strictly net.

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Part II., **Tanning**—Chapter I., The Installation of a Tannary: I., Tan Furnaces; II., Chimneys, Boilers, etc.; III., Steam Engines—Chapter II., Grinding and Trituration of Tanning Substances: I., Cutting up Bark; II., Grinding Bark; III., The Grinding of Tan Woods; IV., Powdering Fruit, Galls and Grains; V., Notes on the Grinding of Bark—Chapter III., Manufacture of Sole Leather: I., Soaking; II., Sweating and Unhairing; III., Plumping and Colouring; IV., Handling; V., Tanning; VI., Tanning Elephants' Hides; VII., Drying; VIII., Striking or Pinning—Chapter IV., Manufacture of Dressing Leather: I., Soaking; II., Depilation; III., New Processes for the Depilation of Skins; IV., Tanning; V., Cow Hides; VI., Horse Hides; VII., Goat Skins; Manufacture of Split Hides—Chapter V., On Various Methods of Tanning: I., Mechanical Methods; II., Physical Methods; III., Chemical Methods; IV., Tanning with Extracts—Chapter VI., Quantity and Quality: I., Quantity; II., Net Cost; III., Quality of Leather—Chapter VII., Various Manipulations of Tanned Leather: I., Second Tanning; II., Grease Stains; III., Bleaching Leather; IV., Waterproofing Leather; V., Weighting Tanned Leather; VI., Preservation of Leather—Chapter VIII., Tanning Various Skins.

Part III., **Currying**—Chapter I., Waxed Calf: I., Preparation; II., Shaving; III., Stretching or Slicking; IV., Oiling the Grain; V., Oiling the Flesh Side; VI., Whitening and Graining; VII., Waxing; VIII., Finishing; IX., Dry Finishing; X., Finishing in Colour; XI., Cost—Chapter II., White Calf: I., Finishing in White—Chapter III., Cow Hide for Upper Leathers: I., Black Cow Hide; II., White Cow Hide; III., Coloured Cow Hide.—Chapter IV., Smooth Cow Hide—Chapter V., Black Leather—Chapter VI., Miscellaneous Hides: I., Horse; II., Goat; III., Waxed Goat Skin; IV., Matt Goat Skin—Chapter VII., Russia Leather: I., Russia Leather; II. Artificial Russia Leather.

Part IV., **Enamelled, Hungary and Chamoy Leather, Morocco, Parchment, Furs and Artificial Leather**—Chapter I., Enamelled Leather: I., Varnish Manufacture; II., Application of the Enamel; III., Enamelling in Colour—Chapter II., Hungary Leather: I., Preliminary; II., Wet Work or Preparation; III., Aluming; IV., Dressing or Loft Work; V., Tallowing; VI., Hungary Leather from Various Hides—Chapter III., Tawing: I., Preparatory Operations; II., Dressing; III., Dyeing Tawed Skins; IV., Rugs—Chapter IV., Chamoy Leather—Chapter V., Morocco: I., Preliminary Operations, II., Morocco Tanning: III., Mordants used in Morocco Manufacture; IV., Natural Colours used in Morocco Dyeing; V., Artificial Colours; VI. Different Methods of Dyeing; VII., Dyeing with Natural Colours; VIII., Dyeing with Aniline Colours; IX., Dyeing with Metallic Salts; X., Leather Printing; XI., Finishing Morocco; XII., Shagreen; XIII., Bronzed Leather—Chapter VI., Gilding and Silvering: I., Gilding; II., Silvering; III., Nickel and Cobalt—Chapter VII., Parchment—Chapter VIII., Furs and Furriery: I., Preliminary Remarks; II., Indigenous Furs; III., Foreign Furs from Hot Countries; IV. Foreign Furs from Cold Countries; V., Furs from Birds' Skins; VI., Preparation of Furs; VII., Dressing; VIII., Colouring; IX., Preparation of Birds' Skins; X., Preservation of Furs—Chapter IX., Artificial Leather: I., Leather made from Scraps; II., Compressed Leather; III., American Cloth; IV., Papier Mâché; V., Linoleum; VI., Artificial Leather.

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Part VI., **Uses of Leather**—Chapter I., Machine Belts: I., Manufacture of Belting; II., Leather Chain Belts; III., Various Belts, IV., Use of Belts—Chapter II., Boot and Shoemaking: I., Boots and Shoes; II., Laces—Chapter III., Saddlery: I., Composition of a Saddle; II., Construction of a Saddle—Chapter IV., Harness: I., The Pack Saddle; II., Harness—Chapter V., Military Equipment—Chapter VI., Glove Making—Chapter VII., Carriage Building—Chapter VIII., Mechanical Uses.

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Mitrons, Lanterns, Chimneys—Qualities of Tiles—Black Tiles—Stoneware Tiles—Particulars of Tiles. Chapter V., Pipes: I. Conduit Pipes—Manufacture—Moulding: Horizontal Machines, Vertical Machines, Worked by Hand and Steam—Particulars of these Machines—Drying—Firing—II. Chimney Flues—Ventiducts and "Boisseaux," "Waggons"—Particulars of these Products. Chapter VI., Quarries: 1, Plain Quarries of Ordinary Clay; 2, of Cleaned Clay—Machines, Cutting, Mixing, Polishing—Drying and Firing—Applications—Particulars of Quarries. Chapter VII., Terra-cotta: History—Manufacture—Application: Balustrades, Columns, Pilasters, Capitals, Friezes, Frontons, Medallions, Panels, Rose-windows, Ceilings—Appendix: Official Methods of Testing Terra-cottas.

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## Contents.

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(The Study of the Raw Materials and the Technology of the Spinning Process.) Text-book for Textile, Trade and Higher Technical Schools. By Julius Zipser. Translated from German by Charles Salter. 302 Illustrations. 480 pp. Demy 8vo. 1901. Price 10s. 6d.; India and Colonies, 11s.; Other Countries, 12s.; strictly net.

### Contents.

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